ACRP

REPORT 78

AIRPORT
COOPERATIVE
RESEARCH
PROGRAM

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Airport Ground Support Equipment (GSE): Emission Reduction Strategies, Inventory, and Tutorial

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

AIRPORT COOPERATIVE RESEARCH PROGRAM

ACRP REPORT 78

Airport Ground Support Equipment (GSE): Emission Reduction Strategies, Inventory, and Tutorial

CDM Federal Programs Corporation
Cambridge, MA

KB Environmental Sciences, Inc.
St. Petersburg, FL

Ricondo & Associates, Inc.
Chicago, IL

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AIRPORT COOPERATIVE RESEARCH PROGRAM

Airports are vital national resources. They serve a key role in transportation of people and goods and in regional, national, and international commerce. They are where the nation's aviation system connects with other modes of transportation and where federal responsibility for managing and regulating air traffic operations intersects with the role of state and local governments that own and operate most airports. Research is necessary to solve common operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the airport industry. The Airport Cooperative Research Program (ACRP) serves as one of the principal means by which the airport industry can develop innovative near-term solutions to meet demands placed on it.

The need for ACRP was identified in *TRB Special Report 272: Airport Research Needs: Cooperative Solutions* in 2003, based on a study sponsored by the Federal Aviation Administration (FAA). The ACRP carries out applied research on problems that are shared by airport operating agencies and are not being adequately addressed by existing federal research programs. It is modeled after the successful National Cooperative Highway Research Program and Transit Cooperative Research Program. The ACRP undertakes research and other technical activities in a variety of airport subject areas, including design, construction, maintenance, operations, safety, security, policy, planning, human resources, and administration. The ACRP provides a forum where airport operators can cooperatively address common operational problems.

The ACRP was authorized in December 2003 as part of the Vision 100-Century of Aviation Reauthorization Act. The primary participants in the ACRP are (1) an independent governing board, the ACRP Oversight Committee (AOC), appointed by the Secretary of the U.S. Department of Transportation with representation from airport operating agencies, other stakeholders, and relevant industry organizations such as the Airports Council International-North America (ACI-NA), the American Association of Airport Executives (AAAE), the National Association of State Aviation Officials (NASAO), Airlines for America (A4A), and the Airport Consultants Council (ACC) as vital links to the airport community; (2) the TRB as program manager and secretariat for the governing board; and (3) the FAA as program sponsor. In October 2005, the FAA executed a contract with the National Academies formally initiating the program.

The ACRP benefits from the cooperation and participation of airport professionals, air carriers, shippers, state and local government officials, equipment and service suppliers, other airport users, and research organizations. Each of these participants has different interests and responsibilities, and each is an integral part of this cooperative research effort.

Research problem statements for the ACRP are solicited periodically but may be submitted to the TRB by anyone at any time. It is the responsibility of the AOC to formulate the research program by identifying the highest priority projects and defining funding levels and expected products.

Once selected, each ACRP project is assigned to an expert panel, appointed by the TRB. Panels include experienced practitioners and research specialists; heavy emphasis is placed on including airport professionals, the intended users of the research products. The panels prepare project statements (requests for proposals), select contractors, and provide technical guidance and counsel throughout the life of the project. The process for developing research problem statements and selecting research agencies has been used by TRB in managing cooperative research programs since 1962. As in other TRB activities, ACRP project panels serve voluntarily without compensation.

Primary emphasis is placed on disseminating ACRP results to the intended end-users of the research: airport operating agencies, service providers, and suppliers. The ACRP produces a series of research reports for use by airport operators, local agencies, the FAA, and other interested parties, and industry associations may arrange for workshops, training aids, field visits, and other activities to ensure that results are implemented by airport-industry practitioners.

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The research was led by John Pehrson, P.E., of CDM Smith as the Principal Investigator. He was assisted by Selena Gallagher, Shannetta Griffin, Wei Guo, William Lott, Michael Miller, Gwen Pelletier, Rob Saikaly, George Siple, and Dee Warren—all of CDM Smith. In addition, Michael Kenney, Carrol Fowler, Paul Sanford, Mike Ratte, and Wayne Arner, all of KBE, and John Williams, Philip Hogg, Casey Venzon, and Jason Apt of Ricondo & Associates, Inc. served as subcontractors to CDM Smith.

The research team would like to express its gratitude to the members of the ACRP Project 02-16 panel for the input throughout this research project. The research team would also like to thank the staff members of those regional and international airports that participated in this research, including Boise (BOI), Boston Logan (BOS), Dallas-Ft. Worth (DFW), Detroit Wayne County (DTW), Fresno-Yosemite (FAT), Front Range (FTG), Manchester-Boston (MHT), Minneapolis-St. Paul (MSP), Sacramento (SMF), Seattle-Tacoma (SEA), Tampa (TPA), and Tucson (TUS). The research team also acknowledges and gratefully thanks all of the airlines that participated in the project, as well as the numerous GSE vendors that offered information and support.

FOREWORD

By Theresia H. Schatz
Staff Officer
Transportation Research Board

To help the industry assess and mitigate the contribution of ground support equipment (GSE) to air quality impacts at airports, *ACRP Report 78* (1) presents an inventory of GSE at airports, (2) identifies potential strategies to reduce emissions from powered GSE, and (3) provides a tutorial that describes GSE operations and emission reduction technologies for use by GSE owners and operators.

The tutorial is a user-friendly, interactive, self-paced, stand-alone tool that provides stakeholders a better understanding of GSE, their operations, and applicable federal environmental regulations and potential approaches to reduce GSE emissions. The tutorial is structured in three modules: GSE Basics, Emissions Reduction Approaches and Case Studies, and Converting to Cleaner GSE.

Increased levels of demand at airports in the United States may result in a growth in airport ground support equipment (GSE) activity and an associated increase in airport surface emissions. Local air quality and global climate change concerns, regulatory pressures, and the desire to be environmentally responsible have resulted in a growing number of airport programs around the United States looking to assess and reduce airport emissions. Although much is known about aircraft fleets, operations, and emissions, comparatively little is known about GSE. The available GSE data are outdated, unreliable, and limited. Accurate GSE data are needed by the FAA and airport sponsors to plan adequately and to balance the growing demands of air travel with air quality concerns. Proactive strategies that reduce surface emissions may help airports address air quality concerns. As such, this research provides additional information on GSE and identifies programs and best practices that could reduce GSE emissions for GSE owners, operators, and airports.

This report was developed from the research conducted for ACRP Project 02-16, "Airport Ground Support Equipment (GSE) Inventory and Emission Reduction Strategies," by CDM Smith in association with KB Environmental Sciences, Inc., and Ricondo & Associates, Inc.; includes a representative database of GSE; and the tutorial contained on the accompanying CD.

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Note: Many of the photographs, figures, and tables in this report have been converted from color to grayscale for printing. The electronic version of the report (posted on the Web at www.trb.org) retains the color versions.

CHAPTER 1

Background

This section provides background information on the original problem statement and research objectives for ACRP Project 02-16 ["Airport Ground Support Equipment (GSE) Inventory and Emission Reduction Strategies"].

1.1 Problem Statement and Research Objective

The original problem statement and objectives for ACRP 02-16 as developed by the project panel are restated as follows:

> Increased levels of demand at airports in the United States may result in a growth in airport GSE activity and an associated increase in airport surface emissions. Local air quality and global climate change concerns, regulatory pressures, and the desire to be environmentally responsible have resulted in a growing number of airport programs around the United States looking to assess and reduce airport emissions.
>
> Although much is known about aircraft fleets, operations, and emissions, comparatively little is known about GSE. The available GSE data are outdated, unreliable, and limited. Accurate GSE data are needed by the FAA and airport sponsors to plan adequately and to balance the growing demands of air travel with air quality concerns.
>
> Proactive strategies that reduce surface emissions may help airports address air quality concerns. As such, research is needed to obtain additional information on GSE equipment and to identify programs and best practices that could reduce GSE emissions for GSE owners, operators, and airports.

In response to this problem statement, the primary objectives of this research were to (1) develop a tutorial that describes GSE operations and identifies potential strategies to reduce emissions from powered GSE for use by GSE owners and operators and (2) conduct a representative inventory of powered GSE at airports to help the industry assess the contribution of GSE to air quality impacts at airports.

1.2 Scope of the Research Project

The scope of the research project comprised nine tasks, which are discussed in the next chapter.

CHAPTER 2

Research Approach

In accordance with the original concept developed by the ACRP panel for conducting the research, the approach for completing the assignment followed a two-phase, nine-task working plan described in the following paragraphs and illustrated in Figure 2-1.

Task 1

[Define and identify powered GSE types and how the equipment is used at a variety of airports ranging from non-hub to large hub, both in warm and cold climates, taking into consideration airport equipment requirements (e.g., fuel delivery systems and cargo).]

The principal aim of this task was to obtain, compile, and summarize all that is presently known, being planned, and/or forecasted in connection with the types of GSE at airports of every size (i.e., large, medium, small) and function [i.e., hub, non-hub, general aviation (GA)] and how the equipment is used under varying operational, climate, and infrastructure conditions. Serving as the basis, or foundation, upon which this research project was ultimately constructed, this compendium served several important purposes including:

- Provided a comprehensive and "up-to-date" portrayal of the U.S. airport GSE fleets;
- Served as the basis for the research conducted under Tasks 3 (Economic and Environmental Considerations), 5 (GSE Tutorial), and 7 (GSE Inventory); and
- Aided in identifying any important weaknesses, discrepancies, or gaps in the available data and information.

Task 2

[Identify the federal regulations and programs that govern emissions for powered GSE that were identified in Task 1.]

The purpose of this task was to identify and describe federal regulations and programs that govern emissions for the GSE identified in Task 1. This information was considered central to the outcomes and applications of this project as the information can both help and hinder programs, actions, or initiatives that are designed to reduce GSE emissions. Examples include the federal Clean Air Act (CAA) and the FAA Voluntary Airport Low Emissions Program. Because some state-level regulations also apply to GSE, they are also mentioned.

Task 3

[Based on the results of Task 1, provide a detailed review of the economic and environmental considerations and challenges associated with owning and operating GSE.]

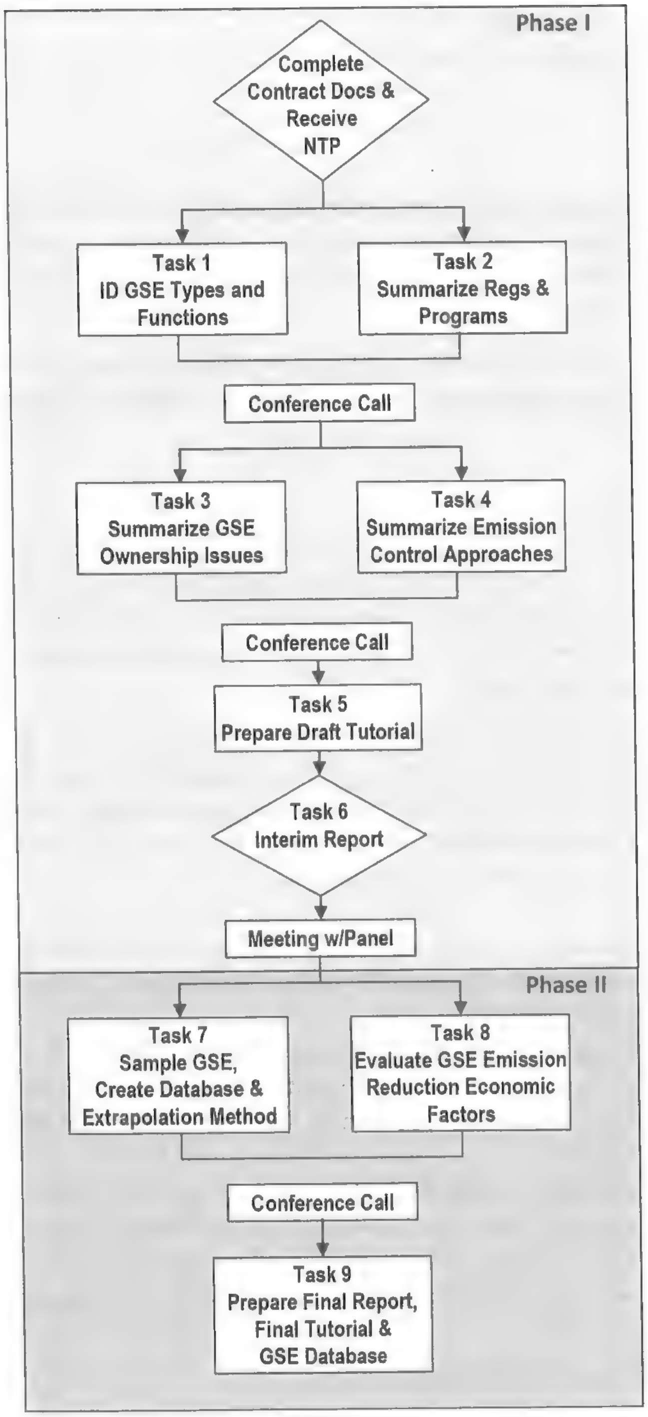


Figure 2-1. ACRP 02-16 work plan.

With the principal aim of comparing GSE powered with conventional (i.e., diesel and gasoline) fuels to those powered with alternative fuels (i.e., ethanol, biodiesel, natural gas, propane, methanol, hydrogen and electricity), the following factors were evaluated:

- Fuel availability and costs,
- Performance characteristics and energy efficiency,
- Training and storage requirements,

- Emission reduction potentials, and
- Environmental and safety considerations.

Task 4

[Identify operational approaches that have been implemented at various airports to reduce GSE emissions. Include voluntary approaches from both U.S. airports and non-U.S. airports that may be applicable to U.S. airports. Identify and describe potential incentives, hurdles faced, and realized benefits of these approaches.]

Under this task, a number of operational approaches that have been implemented at both U.S. and non-U.S. airports to reduce emissions from GSE were identified and summarized.

Task 5

[Develop a GSE tutorial based on the results of Tasks 1 through 4. This tutorial is intended to be a stand-alone document to provide stakeholders with a better understanding of GSE, their operations, and applicable federal environmental regulations and potential approaches to reducing GSE emissions. It should include illustrations and basic technical data including approximate cost range forecast for each type of equipment by fuel type.]

This task included development of a GSE tutorial as a user-friendly, interactive, and self-paced tool for learning about GSE and their functions, and alternative fuels and their emission reduction potentials. Users can "point and click" their way through convenient, easy-to-follow synopses of the materials in a fashion that helps users synthesize and apply the knowledge to real-world practice. The tutorial is structured in three modules:

- **Module 101, GSE Basics,** includes the types and functions of GSE, usage considerations, alternative fuels, air quality impacts, environmental regulations, and a primer of air quality science and policy principles.
- **Module 201, Emissions Reduction Approaches and Case Studies,** addresses emissions reduction approaches applicable to GSE including infrastructure improvements, vehicle retro-fitting, alternative-fuel usage, and operation/maintenance strategies. Airport and airline case studies are also presented.
- **Module 301, Converting to Cleaner GSE,** summarizes economic costs and environmental trade-offs of using cleaner GSE (where available), lists available vendors and distributors of both conventional-fuel and alternative-fuel GSE, and presents life-cycle (i.e., "well to wheels") considerations that GSE owners and operators should keep in mind during their decision-making processes.

The tutorial is on the CD bound into this report.

Task 6

[Prepare an interim report that includes (1) the GSE tutorial developed in Task 5 and (2) an updated Phase II work plan. The work plan should identify sources of data (including existing GSE inventories), potential data gaps, proposed plans for addressing data gaps and the approach for data extrapolation, and proposed structure for the electronic database.]

Under this task, the interim report was prepared that summarized the findings of Tasks 1 through 4, presented the tutorial concept developed under Task 5, and updated the work plan to complete Phase II of the project.

Task 7

[Prepare an inventory of powered GSE that is based on a specific sampling of large-hub, medium-hub, small-hub, and non-hub airports and is representative of airports located in varying climates, with varying airport equipment requirements (e.g., fuel delivery systems and cargo operations). The inventory is to include GSE-specific factors including fuel type, equipment age, anticipated equipment life expectancy, and data related to use (e.g., mileage, hours of operation).]

In-the-field surveys of GSE at 12 airports were conducted that together characterized the varying size and climate conditions that are expected to have an affect on the GSE population and fleet. These data were supplemented with GSE population data obtained from a number of airlines as well as data collected previously by members of the research team. From these expansive and multi-faceted data sets, a comprehensive statistical process was undertaken resulting in a national database of GSE. Segregated by equipment and fuel types, that database can be used as the basis for developing national GSE emission inventories.

Task 8

[Evaluate GSE economic factors including answering the following questions: (1) What alternative fuels are appropriate and available for GSE equipment types; (2) What is the range of costs for infrastructure for each alternative-fuel type; (3) What are the relative costs for retrofits vs. purchasing new equipment; and (4) What are the qualitative considerations an airline and airport must take into account concerning operating GSE?]

For the purposes of this task, much of the information collected and developed under Task 3 was restructured to provide succinct and straight-forward answers to the four proposed questions.

Task 9

[Submit a final report that documents the methodology and findings of the research associated with Tasks 1 through 8, the final GSE tutorial as a stand-alone document, and the finalized equipment inventory in the form of an electronic database.]

This report is the final report under Task 9. The tutorial and the equipment inventory, a Microsoft® Excel™ spreadsheet, are available on the accompanying CD.

The research study findings and conclusions are presented in the next chapter.

CHAPTER 3

Research Findings and Products

The essential outcomes and products of the research are presented in the following sections.

3.1 GSE Types and Functions

Prepared in conjunction with Task 1, the following materials identify the different kinds of GSE and how they are used at airports of varying functions (i.e., hub and non-hub), sizes, and locations.

3.1.1 Types and Functions

Most GSE are typically associated with the servicing of aircraft during the airport turnaround process consisting of the ground operations that are undertaken from the time the rubber blocks (chocks) are placed in front of the aircraft wheels until the time the blocks are removed and the aircraft is ready to leave the gate. During this period, there are a number of tasks that are performed including loading and unloading passengers and baggage, aircraft cleaning and maintenance, refueling and replenishment of provisions, and other similar services. Other common GSE functions pertain to the servicing and maintenance of the airside infrastructure and airfield of the airport. For the purpose of this research, GSE types are categorized by the use of the equipment as follows:

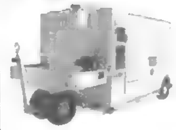
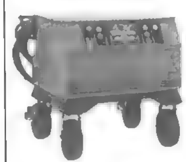
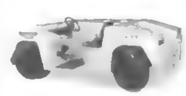
- Providing ground power and air conditioning to an aircraft;
- Moving an aircraft (e.g., out of a gate, to/from maintenance);
- Servicing an aircraft between flights (e.g., replenishing supplies, deicing, etc.);
- Loading/unloading passengers;
- Loading and unloading baggage and cargo; and
- Servicing the airport's ramps, runways, and other areas (e.g., snow removal and lawn maintenance equipment).

A summary description of the GSE types and functions is provided in Table 3-1. Notably, the types of GSE are limited to "powered" GSE and do not include non-motorized equipment such as baggage carts, fuel carts, mobile storage tanks, etc.

3.1.2 GSE Use Considerations

Importantly, not every type of GSE in Table 3-1 is used at every airport in the United States. Factors such as airport type (e.g., general aviation, commercial), the amount of activity at an airport, the size/use of the aircraft using the airport (e.g., wide body, narrow body), tenant use (i.e.,

Table 3-1. GSE types and functions.

Category	Category Description	GSE	GSE Description
Ground power/air conditioning	Used to help start the engines, operate instruments and provide for passenger comfort (e.g., lighting, air conditioning) while an aircraft is on the ground.	Air starter 	Vehicle with a built-in engine which, when aircraft engines are started, provides air for the initial rotation of a large engine.
		Ground power unit (GPU) 	Mobile generators that provide power to parked aircraft when an aircraft's engines are not in use. Typically not used when an airport has gate power systems [i.e., 400 Hertz (Hz)]. Can also be used to start aircraft engines.
		Air conditioning units 	Also referred to as air carts, these units provide conditioned (i.e., cooled and heated) air to ventilate parked aircraft. At some larger airports, individual packaged assemblies or centralized electrical-powered pre-conditioned air (PCA) systems are used.
Aircraft movement	Although an aircraft's engines are capable of moving an aircraft in reverse, this is not typically done for aircraft with jet engines due to the resulting "jet blast" that would occur at the back of the aircraft. For this reason, and others, pushback tugs/tractors are used to maneuver aircraft away from (i.e., out of) gates.	Pushback tugs/tractors 	Used to move an aircraft out of a gate when a pilot is given clearance to taxi to a runway. May also be used to move an aircraft to various locations on an airport (e.g., maintenance hangars). There are two types of pushback tugs/tractors: (1) conventional and (2) towbarless. Conventional tugs use towbars that are connected to an aircraft's nose wheel. Towbarless tractors scoop up the nose wheel and lift it off the ground.
Aircraft service	Aircraft service activities include replenishing supplies and aircraft refueling.	Catering truck 	Typically owned and operated by airlines and companies that specialize in airline catering (e.g., preparing and supplying packaged food). Services provided include removal of unused food/drinks and loading of these items for the next flight.
		Cabin service vehicles 	The main cabin service activities are cleaning the passenger cabin and replenishing items such as soap, pillows, and blankets.

(continued on next page)

Table 3-1. (Continued).

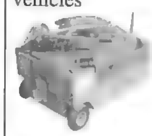
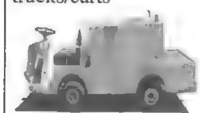
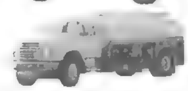
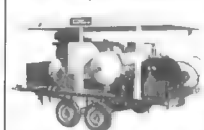
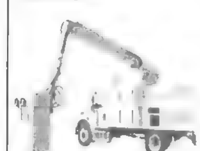
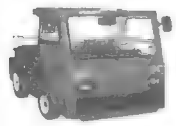
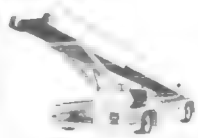
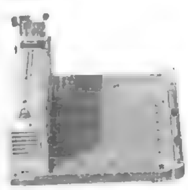
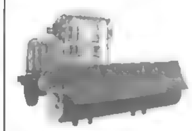
Category	Category Description	GSE	GSE Description
		Lavatory service vehicles 	Used to flush aircraft lavatory systems. Small commuter and regional aircraft used for short flights may not be equipped with on-board lavatories.
		Potable water trucks/carts 	These trucks provide drinkable water to an aircraft.
		Aviation fuel trucks, hydrant dispenser trucks/carts  	Two methods are used to fuel aircraft. The first dispenses fuel from a fuel truck/tanker directly to an aircraft's tank(s). The second method of dispensing fuel is used at airports with underground fueling systems and employs hydrant trucks/carts as "connectors" between the underground fueling system and aircraft.
		Hydrant pit cleaners 	Used at airports with underground fueling systems. Flushes and cleans hydrant pits.
		Maintenance vehicles 	Various types of vehicles are used to provide aircraft maintenance service. These vehicles are used by airport and/or airline employees to travel to/from maintenance facilities and an aircraft in need of repair.
		Deicers 	Vehicles that are used to transport, heat, and spray deicing fluid on an aircraft prior to departure.
Passenger loading/ unloading	Methods vary depending on airport, aircraft, and available airport equipment/facilities. Two methods are used to board passengers onto large aircraft—boarding stairs and jet bridges.	Boarding stairs 	Whether towed, pushed into position, or fixed to a truck, boarding stairs provide a means of loading and unloading passengers at hardstands (i.e., remote parking positions) and in the absence of jet bridges.
		Buses 	On the airside of a large airport, buses may be used to transport passengers and employees from terminal to terminal (or aircraft). Referred to as "people movers," "mobile passenger lounges," and "moon buggies."

Table 3-1. (Continued).

Category	Category Description	GSE	GSE Description
Baggage/cargo handling	Passenger baggage/some cargo must be transferred to/from gates and from gate to gate. Cargo-only aircraft typically have one or more large doors to facilitate loading/unloading of goods.	Baggage tugs 	Most recognizable type of GSE at an airport. These vehicles are used to transport luggage, mail, and cargo between an aircraft and the airport terminal and/or processing/sorting facilities.
		Belt loaders 	Used to load and unload baggage and cargo into/from an aircraft.
		Cargo/container loaders 	Used to load and unload the cargo on an aircraft that is within a container or on a pallet.
		Cargo transportation/ tractors 	Used to load and unload cargo but are primarily used to move cargo from one airport location to another.
		Forklifts 	Cargo is moved primarily by forklifts within airport cargo handling facilities.
		Conveyors	At larger airports, there has been a recent trend to move baggage between concourse collection areas and to/from the concourse collection areas and the terminal baggage claim areas using conveyor systems. Installation of such conveyor systems can significantly reduce the run time for baggage tugs and/or reduce the number of baggage tugs at an airport.
Airport service	Various types of GSE are used by ground crews (airline and/or airport) to service airports.	Snow removal equipment 	Airports use snow removal equipment to keep runways, taxiways, and ramp areas free of snow and ice. Can include snowplows, snow sweepers, and snow blowers. Snow sweepers, typically used in areas with low snow tolerance (i.e., runways), use brushes to remove thin layers of snow from pavement services. Snow blowers are sometimes used instead of snowplows. This type of vehicle uses spinning blades that force the snow out of a "funnel" on the top of the blower.

(continued on next page)

Table 3-1. (Continued).

Category	Category Description	GSE	GSE Description
		Foreign object debris (FOD) removal 	The removal of FOD can be accomplished using mechanical systems (power sweeper trucks, vacuum systems, and jet air blowers) and non-mechanical systems (e.g., tow-behind trailers equipped with brushes, magnetic bars).
		Bobtail trucks	A bobtail is an on-road truck that has been modified to tow trailers and equipment. Bobtails are also used at some airports to plow snow.
		Miscellaneous equipment 	Includes the non-road equipment used by an airport's ground crew to maintain the airport airside environs. This GSE includes generators and lawn mowers. Select on-road equipment such as tow trucks (pictured) can also fall into this category.

hub or non-hub), an airport's geographic location (i.e., warm or cold climate), available infrastructure (e.g., number of gates, underground fueling system), and airport capacity all influence not only the type of GSE but also the number of pieces of GSE in use. Notably, equipment "engine on"/run times can also be affected by these factors.

These factors may affect the type and quantity of GSE at airports as follows:

- **Airport type:** The number and type of GSE in use at an airport is directly related to the type of airport (which also determines the type/size of aircraft using the airport). At an airport that exclusively serves general aviation aircraft, one would not expect to find a significant amount or a wide variety of GSE. By comparison, a large commercial airport located in a metropolitan area typically has a large number of daily operations that requires an extensive inventory of GSE be readily available.
- **Airport activity:** Generally, the greater the number of operations at an airport, the more GSE will be required to provide an acceptable level of service.
- **Aircraft size/use:** Large and medium size passenger air carrier aircraft (e.g., B777, B747, MD11) are referred to as "wide body" aircraft. These aircraft may carry passenger baggage in containers and have a significant amount of cargo to be loaded/unloaded. Smaller passenger air carrier aircraft (e.g., B737, A319) are referred to as "narrow body" aircraft. The amount of passenger baggage and cargo onboard this size aircraft will require smaller or fewer types of GSE to complete necessary gate handling procedures. Regional/business jets and turboprop aircraft (such as the Embraer Legacy 600/145 and Beechcraft Super King Air) have built-in passenger stairs and typically do not carry cargo. Finally, general aviation propeller aircraft and helicopters carry limited baggage, if any, and no cargo and require only limited handling at airports.
- **Hub/non-hub:** Because more aircraft operations occur at hub airports than non-hub airports, more GSE are typically required. Further, while the use of the equipment would be the same regardless of the airport designation (i.e., baggage tugs would still be used to transfer baggage), the number of pieces of equipment required may be more if scheduling (turnaround) times are limited (i.e., more tugs are needed to transfer baggage to individual flights).
- **Climate:** In cold climates with freezing temperatures and precipitation, aircraft and airport surfaces must be deiced and/or snow must be removed. To remove ice from aircraft, deicers are used.

Among other factors, the number of deicing vehicles that are required depends on the severity and frequency of conditions requiring deicing and the number of operations at an airport.

- **Infrastructure:** The available infrastructure at an airport can negate the need for certain types of GSE or reduce an airport's dependence on some GSE. As described in Table 3-1, aircraft are refueled using one of two methods: (1) fuel tankers and (2) underground fueling systems. If an airport has an underground fueling system, fuel is transferred with a hydrant vehicle or a hydrant cart and fuel tankers are not needed.
- **Capacity:** An airport's available capacity can also affect the type and number of GSE in use at an airport. For example, if the number of operations in a given time period exceeds the number of available gates, airports may "hardstand" the "extra" aircraft. A hardstand is a hard surface area that is typically located away from an airport's concourses or terminal. Depending on the size of the aircraft, hardstanding an aircraft will require the use of buses (or "mobile lounges") to transport passengers to/from the aircraft and the use of mobile ground power/air conditioning units for the purpose of performing instrument checks, starting engines, and passenger comfort.

Table 3-2 provides a summary list—by airport type, climate, and intended purpose/utility—of the most common types of GSE used at airports.

3.1.3 GSE Suppliers

During the course of the project, the research team contacted more than 40 GSE suppliers. Representing vendors that manufacture GSE and distribute and/or rent new and refurbished GSE, these companies provide more than 550 models of various types of GSE. For informational purposes, the types of GSE currently manufactured/distributed by these and other vendors are listed in Appendix A.

3.2 Federal Regulations and Programs Applicable to GSE

Prepared in support of Task 2, this section identifies and describes the federal regulations and initiatives pertinent to GSE. However, because several state- and local-level regulations and programs are noteworthy, they are also briefly reported upon here.

3.2.1 Federal Regulations

The federal CAA provides the underlying authority for the protection of the public health and welfare and the environment from air pollution nationwide. It also prescribes the regulation of air emissions from the vast majority of man-made sources, including GSE. The overriding responsibility for the management of ambient (i.e., outdoor) air quality across the United States is principally vested to the U.S. Environmental Protection Agency (EPA).

As a means to carry out and fulfill these functions, the U.S. EPA has promulgated National Ambient Air Quality Standards (NAAQS) for six "criteria" air pollutants [i.e., carbon monoxide (CO), lead (Pb), ozone (O_3), particulate matter with an aerodynamic diameter of 10 micrometers or less (PM_{10}) and an aerodynamic diameter of 2.5 micrometers or less ($PM_{2.5}$), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2)]. For compliance and air quality management purposes, all areas of the United States are designated with respect to their adherence to the NAAQS.

Specifically, areas that meet the NAAQS are designated as "attainment" and those that do not meet the NAAQS are called "nonattainment" (areas in transition are designated "maintenance"). In nonattainment areas, state implementation plans (SIPs), developed by state and local agencies for U.S. EPA approval, identify the policies, control measures, and time frames that will be

Table 3-2. Common types of GSE and use considerations.

GSE Type	Purpose and Utility	Airport H	Airport N	Climate W	Climate C	Characteristics
Air conditioner	Provides conditioned air to ventilate and cool parked aircraft.	●	●	●	○	Used less in cool climates and at airports with gate air conditioner units.
Air starter	Provides large volumes of compressed air to an aircraft's main engines for starting.	●	●	●	●	Used less at airports with gate electricity. Used for commuter aircraft.
Baggage/cargo tractors	Used to tow baggage carts or freight.	●	●	●	●	Most common GSE type and amenable to alternative fuel power.
Belt loaders	Mobile conveyor belts used to move baggage between the ground and the aircraft hold.	●	●	●	●	Used mostly on narrow and medium body passenger aircraft.
Buses	Shuttles passenger and airport personnel between facility locations.	●	○	●	●	Used mostly at hub airports without people mover systems.
Cabin service truck	Used for cleaning the cabin and replenishing supplies.	●	○	●	●	Commonly classified as on-road vehicles.
Cars/pickup trucks	Move airport personnel around facility for administrative and maintenance purposes.	●	●	●	●	Commonly classified as on-road vehicles.
Carts	Used as personnel carriers.	●	●	●	●	Small gasoline- or electric-powered non-road vehicles.
Catering vehicle	Used to restock drinks/food for passenger meals.	●	○	●	●	Commonly classified as on-road vehicles.
Container loader	Used to load large containers on to large cargo and other aircraft	●	●	●	●	Used for air cargo and wide-body passenger aircraft.
De/anti-icing vehicles	Used to remove ice from aircraft prior to departure.	●	●	○	●	Used more at cold climate airports.
Forklifts	Used to move heavy cargo.	●	●	●	●	Used for air cargo and wide-body passenger aircraft.
Fuel trucks	Used to fuel aircraft in the absence of a hydrant system	●	○	●	●	Used less at airports with fuel hydrants.
Ground power units	Mobile generator units that supply aircraft with electricity while parked.	●	●	●	●	Used less at airports with gate electricity. Used for commuter aircraft.
Hydrant cart/trucks	Used to connect underground fueling system to aircraft.	●	●	●	●	Replacements for fuel trucks at airports with hydrants.
Lavatory service vehicles	Used to remove waste /non-potable water from aircraft lavatories.	●	○	●	●	Commonly classified as on-road vehicles.
Passenger stands	Provides passenger access/egress to aircraft	●	●	●	●	Used mostly for air cargo, chartered, and commuter aircraft.
Sweepers	Used to clean gate area and aprons.	●	●	●	●	Diesel-powered, specialty vehicles.
Tow tugs and pushback tractors	Use to tow and push aircraft in the terminal, ramp, and hangar areas.	●	●	●	●	Most common GSE type and amenable to alternative fuel power.
Water trucks	Used to supply water to aircraft.	●	○	●	●	Commonly classified as on-road vehicles.

H – Hub airports, N – Non-hub airports; W – Warm climate, C – Cold climate; ● Common use, ○ Less use

implemented to achieve the NAAQS. Notably, land under tribal government may prepare and submit a tribal implementation plan (TIP).

The U.S. EPA also establishes emission standards (i.e., limitations on the quantity of pollutants emitted) from most stationary and mobile sources of criteria air pollution (and their precursors). Typically, stationary sources represent "smoke-stack" or permanent (i.e., "fixed") installations and mobile sources are characteristically movable or transportable. A third general category of emissions are area sources comprising construction, agricultural, and other similar activities. The U.S. EPA also sets limitations on emissions of 187 compounds or compound categories of hazardous air pollutants (HAPs).

GSE are commonly classifiable under two subcategories of mobile sources: (1) non-road vehicles (i.e., engines and equipment that would not be expected to travel on public roadways) and (2) on-road motor vehicles (i.e., vehicles that are licensed to travel on public roadways). In some instances, GSE may have on-road capabilities but are used in non-road functions (i.e., cabin service trucks).

The emission standards developed by the U.S. EPA to date have typically been much more stringent (i.e., having much lower allowable emission rates) for on-road vehicles than for non-road equipment. Many GSE types (e.g., catering trucks, cabin service trucks, and crew vans) are built with engines that meet the on-road emission standards. Other GSE types (e.g., belt loaders, aircraft tugs, and bag tugs) are typically built with non-road engines and therefore subject to non-road emission standards. Importantly, the CAA preempts states from adopting or enforcing their own on-road and non-road emission standards, with California being the exception.

Tables 3-3 and 3-4 list and summarize the primary federal statutes and programs relevant to the manufacture, ownership, and operation of GSE.

Table 3-3. Summary of relevant federal statutes and programs pertaining to GSE.

Statute/Program	Statute/Program Section	Airport GSE Relevance
CAA Title I: Part A, Air Quality and Emission Limitations	109 – National Ambient Air Quality Standards 110 – Implementation Plans	Sets standards for health-based air pollutant concentrations in ambient air. Requires states to develop implementation plans to control emissions of criteria pollutants to attain and maintain the National Ambient Air Quality Standards.
CAA Title I: Part D, Plan Requirements for Nonattainment Areas	182 – Plan Submissions and Requirements 187 – Plan Submissions and Requirements	Establishes inspection/maintenance programs for on-road vehicles in ozone nonattainment areas. Establishes inspection/maintenance programs for on-road vehicles in carbon monoxide nonattainment areas.
CAA Title II: Part A: Motor Vehicle Emission and Fuel Standards	202 – Emission Standards for New Motor Vehicles or New Motor Vehicle Engines 211 – Regulation of Fuels 213 – Nonroad Engines and Vehicles	Sets engine exhaust emission standards for "on-road" vehicles (cars, vans, catering vehicles, etc.). Sets limitations on the use of additives and the levels of certain compounds, including sulfur, in motor vehicle fuels. Sets engine exhaust standards for non-road vehicles (e.g., belt loaders, tow tugs, forklifts, etc.).
Vision 100 Century of Aviation Reauthorization Act: FAA Voluntary Airport Low Emission Program	121 – Low-Emission Airport Vehicles and Ground Support Equipment 151 – Increase in Apportionment for, and Flexibility of, Noise Compatibility Planning Programs 158 – Emission Credits for Air Quality Projects 159 – Low-Emission Airport Vehicles and Infrastructure	Provides funding for alternative-fuel vehicles as well as low-emission equipment and infrastructure.
Energy Policy Act of 2005	National Clean Diesel Emissions Reduction Program, also called the Diesel Emissions Reduction Act (DERA), and the SmartWay Program	Provides funding assistance to support the deployment of U.S. EPA-verified and certified technologies to reduce diesel-related emissions.

Table 3-4. Summary of federal regulations potentially applicable to airport GSE.

Citation[a]	Title	Airport GSE Relevance
40 CFR 80	Regulation of Fuels and Fuel Additives	Sets specifications and limitations on fuels and additives for engines used in on-road and non-road vehicles including airport GSE.
40 CFR 85	Control of Air Pollution from Mobile Sources	Contains emission performance warranty and other information for engines used in on-road vehicles including airport GSE.
40 CFR 86	Control of Emissions from New and In-Use Highway Vehicles and Engines	Contains exhaust emission standards for engines used in on-road vehicles including airport GSE.
40 CFR 88	Clean-Fuel Vehicles	Contains exhaust emission standards for centrally fueled fleets such as on-road airport GSE in certain nonattainment areas.
40 CFR 89	Control of Emissions from New and In-Use Nonroad Compression-Ignition Engines	Contains exhaust emission standards (Tiers 1, 2, and 3) for compression-ignition (e.g., diesel) engines used in some non-road vehicles including airport GSE.
40 CFR 93 Subpart A	Conformity to State or Federal Implementation Plans of Transportation Plans, Programs, and Projects Developed, Funded, or Approved under Title 23 U.S.C. or the Federal Transit Laws	Transportation conformity may affect the operation of on-road airport GSE.
40 CFR 93 Subpart B	Determining Conformity of General Federal Actions to State or Federal Implementation Plans	General conformity may affect the operation of on-road and non-road airport GSE.
40 CFR 1039	Control of Emissions from New and In-Use Nonroad Compression-Ignition Engines	Contains exhaust emission standards (Tier 4) for compression-ignition (e.g., diesel) engines used in some non-road vehicles including airport GSE.
40 CFR 1048	Control of Emissions from New, Large Nonroad Spark-Ignition Engines	Contains exhaust emission standards for large spark-ignition (e.g., gasoline) engines used in some non-road vehicles including airport GSE.
40 CFR 1060	Control of Evaporative Emissions from New and In-Use Nonroad and Stationary Equipment	Contains evaporative emission standards for non-road engines including those used in airport GSE.
40 CFR 1068	General Compliance Provisions for Engine Programs	Contains basic compliance requirements for engines including those used in airport GSE.

[a]CFR refers to the Code of Federal Regulations.

3.2.2 Non-road Engine Emission Standards (Compression and Spark Ignition)

Non-road vehicles (including non-road engines and the associated equipment) constitute a broad array of vehicle and equipment types, including aircraft, watercraft, locomotives, recreational vehicles, construction vehicles, farm equipment, and GSE, to name a few. The non-road engines generally fall into two broad classes: (1) compression-ignition (CI) engines and (2) spark-ignition (SI) engines. Typically, non-road CI engines are fueled with diesel while non-road SI engines are traditionally fueled with a more volatile fuel, such as gasoline. With the emergence of alternative fuels and technologies, other fuels are now becoming more common as discussed in Section 3.3.2 (Alternative-Fuel GSE).

Compression-Ignition Engines

Federal emission standards for non-road CI engines have been established for non-methane hydrocarbons (NMHC), oxides of nitrogen (NO_x), particulate matter (PM), CO, and smoke output. The U.S. EPA has organized these emissions standards into classes (or tiers) based on the date

of manufacture and rated engine output (e.g., horsepower) with greater stringency (i.e., lower emissions) associated with increasing emission control levels (i.e., Tier 0 < 1 < 2 < 3 < 4). These emission standards and associated requirements are directed primarily at engine manufacturers, but the owners/operators also bear some responsibilities. For example, manufacturers of non-road CI engines must produce and offer for sale engines that meet the appropriate tier levels of emission standards and provide the necessary maintenance instructions and servicing procedures for the engine owner or operator to follow.

Similarly, it is the responsibility of the owner/operator to follow the manufacturer's maintenance instructions thus enabling the engine to perform as designed and meet the applicable emission standards. These regulations also prohibit the disabling of emission controls on an engine or equipping an engine with an emission defeat device.

It should be noted that, for non-road CI engines greater than 50 horsepower, the useful life is assumed to be 8,000 hours or 10 years, whichever comes first, and the warranty period is 3,000 hours or 5 years, whichever comes first. Owners and operators of CI non-road engines and equipment must also use ultra-low sulfur diesel fuel beginning in 2010.

Spark-Ignition Engines

The federal emission standards for SI non-road engines have been promulgated for equipment produced after 2004 and are also "tiered" to reflect increasing emission controls based on the date of manufacture and horsepower but include both exhaust emission standards and evaporative emission standards. Again, SI non-road engines are traditionally fueled with more volatile fuels, such as gasoline or natural gas, but alternatives to these fuels are emerging.

As with CI engines, the emission standards and associated requirements are directed primarily at engine manufacturers, but the ultimate owner or operator does have some responsibilities related to emissions. Again manufacturers of SI non-road engines must produce and offer for sale engines that meet the appropriate level of emission standards, and provide the necessary maintenance and servicing procedures. Similarly, it is the responsibility of the owner/operator to follow the maintenance and service instructions.

For large SI non-road engines, the useful life is assumed to be 5,000 hours or 7 years (except for severe-duty engines), whichever comes first, and the emission-related warranty period is 2,500 hours or 3 years for exhaust emission controls and at least 2 years for evaporative emission controls. Fuel regulations require that in those parts of the United States with the worst air quality, SI engines must use reformulated or oxygenated gasoline to help reduce the formation of air pollutants.

The U.S. EPA has also published voluntary emission standards for large SI non-road engines known as the "Blue Sky Series" for model years beginning in 2004. These standards, while they are voluntary, are intended to encourage manufacturers to develop innovative technologies to go beyond the required emission standards for these types of engines. Importantly, any manufacturer certifying a class of its engines to the Blue Sky Series standards is required to ensure that the engines adhere to the standards as if they were mandatory.

3.2.3 On-Road Engine Emission Standards (Compression and Spark Ignition)

According to the CAA, the term "motor vehicle" means any self-propelled vehicle designed for transporting persons or property on a street or highway. Thus, a motor vehicle, or on-road vehicle, may belong to any of a number of classes of vehicles, including light-duty vehicles (primarily automobiles and light-duty trucks), medium-duty trucks, heavy-duty trucks, buses, and

other vehicles such as motorcycles. These types of vehicles may be fueled by a variety of types of fuels, including conventional petroleum-based fossil fuels such as gasoline and diesel, and cleaner-burning alternative non-petroleum-based fuels such as natural gas, propane, ethanol, methanol, biodiesel, hydrogen, electricity, and other fuels.

Emission standards for on-road vehicles apply primarily to exhaust (i.e., tailpipe) emissions as well as evaporative emissions and are largely a function of the vehicle's age (i.e., date of manufacture) as well as class of vehicle, type of fuel, and capacity and type of engine. As with non-road engines, engines used in on-road vehicles may be either compression ignition or spark ignition. Generally, the newer on-road vehicles have more restrictive emission standards than the older, preceding models.

In nonattainment areas, owners or operators of centrally fueled fleets may be required to participate in the U.S. EPA's clean fuel fleet program requiring the use of low-emission vehicles (40 CFR 88). Additional standards apply to fuels, fuel additives, and fueling, particularly, limitations on volatile components, sulfur, and certain toxic compounds such as benzene (40 CFR 80).

In those nonattainment areas having a motor vehicle inspection/maintenance (I/M) program to reduce emissions, the vehicle owner/operator is responsible for meeting the state's requirements for periodic inspection and maintenance. Newer vehicles also utilize on-board diagnostics (OBDs) to assist the owner or operator to maintain the vehicle in proper service so that it will continue to meet applicable emission standards. The OBD system is designed to trigger a dashboard "check engine" light as a warning indicator to the driver of a possible malfunction of the engine's emission control system. Each state's I/M program includes an inspection of the OBD system.

3.2.4 Emission Standards in the State of California

As noted in Section 3.2.1, California presents an exception to the federal preemption of state emission standards for mobile sources. For example, Section 209(e) of the CAA allows California to adopt and enforce standards and other requirements relating to the control of emissions from non-road engines or vehicles (other than construction or agricultural engines or vehicles smaller than 175 horsepower and locomotive engines). The only stipulation is that the California standards must be at least as protective of public health and welfare as the applicable federal standards.

Consequently, the California Air Resources Board (CARB) has adopted emission standards that apply to both CI and SI non-road engines and vehicles. Of particular importance to owners/operators of GSE in California is the In-Use Offroad Diesel Vehicle Regulation (13 CCR Article 4.8 Sections 2449, 2449.1, 2449.2, and 2449.3) originally adopted in July 2007. In December 2010, CARB amended the regulation so that owners/operators of non-road CI vehicles greater than 25 horsepower (including GSE) are required to reduce emissions of diesel particulate matter and NO_x.

Importantly, these vehicles are subject to "fleet averaging" to meet the emission standards, which can be accomplished, if necessary, by engine retrofits or fleet turnover. The standard also requires enforcement of a 5-minute idling restriction as well as other requirements. The initial compliance date for the largest fleets is January 1, 2014, and smaller fleets would have later compliance dates.

3.2.5 State Implementation Plans and Emission Budgets

As noted previously, under the federal CAA, each state is required to adopt a SIP that describes how it will implement, maintain, and enforce the NAAQS. In summary, the SIP must contain

enforceable emission limitations and other control measures, means, and techniques as well as schedules and timetables to achieve compliance with the NAAQS.

A SIP attainment or maintenance demonstration relies on detailed analyses of emission levels from stationary and mobile sources, including the degree of reductions of emissions (or reductions in the growth of emissions) and their impact on ambient air quality. From this, the SIP specifies projected future emissions (i.e., emissions budgets) that must be met to achieve the timely attainment and maintenance of the NAAQS. Afterward, the states conduct periodic inventories of emissions from applicable sources for comparison with the emissions budgets to ensure reasonable progress toward meeting the goals of the SIP. If reasonable progress is not being achieved, it may be necessary for a state to impose additional emission limitations or control measures.

An up-to-date and accurate inventory of GSE and the associated emissions is but one component of the SIP emissions inventory. However, because GSE is not always accounted for or is otherwise misrepresented in SIPs, another ACRP research project is under way to improve this process (ACRP 02-21, "Evaluation of Airport Emissions within State Implementation Plans").

Although not directly applicable to emissions from individual on-road vehicles or fleets of vehicles such as GSE, the CAA Transportation Conformity Rule (40 CFR 93 Subpart A) requires metropolitan planning organizations (MPOs) to ensure transportation plans, transportation improvement programs, and transportation projects conform to the purpose of each state's SIP. In this way, air quality conditions do not degrade due to contributions from an area's transportation system, including its on-road vehicles, and may include transportation control measures that impose operating conditions on the area's highway and roadway system. Generally, non-road GSE engines and equipment are not addressed in an area's transportation plan.

Likewise, the CAA General Conformity Rule (40 CFR 93 Subpart B) requires any entity of the federal government (e.g., the FAA) that engages in, supports, or in any way provides financial support for, licenses or permits, or approves any activity (i.e., a "federal action" as defined in 40 CFR 93.152, unless otherwise determined to be exempt or presumed to conform) to demonstrate that the action conforms to the state's SIP. With respect to GSE, the rule compels the airport operator or the project sponsor to account for the GSE emissions and either demonstrate that they are within acceptable thresholds (i.e., de minimis levels) or mitigate the increase in emissions, if necessary.

3.2.6 FAA's Voluntary Airport Low Emission Program

Under the Vision 100 Century of Aviation Reauthorization Act (signed into law in December 2003), the FAA administers the Voluntary Airport Low Emission (VALE) Program. The VALE Program is intended to offer financial and regulatory incentives to commercial service airports to voluntarily reduce emissions of air pollutants in geographical locations of the United States that are classified by the U.S. EPA as having nonattainment (or maintenance) status with respect to the NAAQS.

While numerous types of airport projects are eligible for grants under the VALE Program, generally it focuses on alternative-fuel vehicles and low-emission technology infrastructure. The FAA annually issues updated technical guidance on the VALE Program, addressing eligibility of projects, funding sources, coordination with administering agencies, the process to apply for a VALE grant, and the responsibilities of an airport upon obtaining a grant under the program. The FAA has issued grants under the VALE Program since its inception in federal fiscal year 2005.

Under the VALE Program, grant funds may be requested from either the Airport Improvement Program (AIP) or Passenger Facility Charges (PFC). Under the AIP, funding may come from

either entitlements or from the discretionary "noise and air quality set-aside" budgets. For large or medium hub airports, VALE will reimburse 75 percent of the incremental cost of alternative-fuel vehicles and 75 percent of the total cost of eligible low-emission infrastructure (such as electric charging stations or compressed natural gas fueling stations). For smaller commercial service airports, the reimbursement values are consistent with AIP requirements. Airport matching funds may come from local revenues, state or local grants, or from PFCs. If PFCs are used for matching funds, they become subject to the AIP standard assurances and compliance requirements. To date, all VALE grants issued have been provided under the AIP.

GSE acquired through the VALE Program can be owned by the airport and made available for use (e.g., leased) by another operator, such as an airline or fixed-base operator (FBO) that is a tenant at the airport. The VALE Program also permits an entity other than the airport, such as a tenant airline or FBO, to acquire and use alternative-fuel GSE, but that entity must commit to certain restrictions with regard to the use and disposition of the equipment, and it must honor all applicable AIP grant assurances.

For VALE applications seeking AIP funding, the FAA recommends submitting an application in the spring of the prior federal fiscal year in anticipation of an award in the fall of the following federal fiscal year. An application seeking PFC funding may be submitted at any time.

In the FAA Modernization and Reform Act of 2012 (signed into law by President Obama on February 14, 2012), a pilot program for zero-emission airport vehicles was authorized. The act provides some minimal guidelines for the U.S. Department of Transportation to follow if a program is established. However, the program details have not been developed at this time.

3.2.7 Other Grant Programs

The National Clean Diesel Emissions Reduction Program, which is sometimes referred to as the Diesel Emissions Reduction Act (DERA), was created by the Energy Policy Act of 2005. Under this program, the U.S. EPA has provided funding assistance to support the deployment of U.S. EPA-verified and -certified technologies to reduce diesel-related emissions. The continued funding of DERA is presently pending.

The related "SmartWay" Program allows the U.S. EPA to issue competitive grants to establish national low-cost revolving loans or other financing programs that provide funding for vehicle fleets to reduce diesel emissions. The availability of grant funds depends on annual appropriations and, at any given time, other funding opportunities applicable to GSE may be available from the various U.S. EPA regional offices.

While an airport may seek FAA funding of emission reduction projects through traditional AIP entitlements, a candidate emission reduction project would have to compete against other capital improvement projects, requiring the airport to prioritize projects according to its needs and interests.

The U.S. Department of Energy (DOE) may also provide opportunities for grants applicable to GSE, either through the Energy Efficiency and Renewable Energy (EERE) Program or through the Clean Cities Program. Because these funding mechanisms are constantly evolving, prospective applicants must check program guidance on a regular basis to determine specific opportunities.

Some states provide opportunities for incentive grants and loans to implement emission reduction projects. Examples include the Carl Moyer Program at the California Air Resources Board and the Emission Reduction Incentive Grant Program at the Texas Council on Environmental Quality. Prospective applicants should check with their state's air quality regulatory agency on the availability of such programs and the associated eligibility requirements.

3.3 Air Emission Mitigation Strategies Applicable to GSE

This section identifies and discusses various approaches that have been implemented at airports to reduce air emissions from GSE. In addition, the available incentives, the benefits gained, and the potential barriers to attaining emission reductions associated with GSE are also discussed. For ease of comprehension, the prevailing approaches are described first followed by specific airport examples of GSE emission reduction measures.

3.3.1 Equipment-Related Approaches

Equipment-related approaches to reducing emissions from GSE characteristically comprise (1) the use of infrastructure or hardware systems as an alternative to GSE, (2) the use of add-on control devices on conventional-fuel GSE, and (3) the use of the advanced fuel combustion technologies for conventional-fuel GSE.

Infrastructure and Hardware Systems

In some cases, the primary functions of select types of GSE can be replaced by incorporating fixed point-of-use support equipment into airport terminal gate design. One common example involves terminal gate electrification through the use of (1) fixed preconditioned air (PCA) systems replacing diesel-powered air conditioning units (ACUs) and (2) 400 Hz electrical systems to replace diesel-powered ground power units (GPUs) and aircraft air start units (ASUs). Although many aircraft use on-board jet fuel-powered auxiliary power units (APUs) to perform these necessary functions, the PCA and 400 Hz systems eliminate the need for such GSE and minimize APU use. Notably, APU usage at the gate cannot be eliminated completely as it is required during preflight checks and aircraft main engine startup.

As discussed in Section 3.2, eligible airports can obtain funding under the FAA VALE Program for these qualified infrastructure projects that reduce air emissions. For example, the Seattle-Tacoma International Airport (SEA) recently obtained VALE funding for the installation of PCA at 82 gates and the Gerald R. Ford International Airport (GRR) obtained VALE funding for PCA and 400 Hz power at five gates.

Another infrastructure GSE emission reduction example is the use of in-ground hydrant fueling systems in place of mobile refuelers thereby decreasing engine emissions associated with these trucks. Most fuel hydrant systems still require an interface between the in-ground system and the aircraft, commonly provided by an engineless fuel cart or a fuel pumping truck powered by a conventional-fuel engine.

Importantly, such infrastructure projects are less costly to install when designed as part of new facilities rather than as retrofits to existing facilities. For example, a gate electrification project may require an upgrade to the power supply to the terminal building, electrical improvements at the terminal gate, and power improvements within the gate area. Installing a fuel hydrant system at existing airport facilities can also be relatively expensive as well as disruptive of operations in the terminal gate area because it requires belowground installation.

Installing more advanced systems to replace GSE (e.g., a centralized conveyer belt-driven baggage distribution and delivery system to replace baggage tugs and belt loaders) are also possible. However, the costs and cost effectiveness for these types of infrastructure improvements are difficult to generalize and would need to be evaluated on a case-by-case basis.

Add-on Emission Control Devices

Engine exhaust after-treatment systems have been successfully used in on-road vehicles for more than 35 years to reduce emissions. In general, these control devices serve to collect and convert the exhaust emissions to more environmentally friendly compounds before they are

discharged into the atmosphere. The following examples of exhaust after-treatments are applicable to GSE:

- **Oxidation catalysts:** At the most basic level, oxidation catalysts use a material such as platinum to more efficiently oxidize unburned hydrocarbons and CO in the engine exhaust to carbon dioxide (CO_2) and water.
- **Three-way catalytic converters:** These devices oxidize unburned hydrocarbons and CO to CO_2 and water, but also reduce NO_x to molecular nitrogen and oxygen. These devices have been particularly successfully in on-road vehicles in the form of catalytic converters but are currently only compatible with spark-ignition engines. The removal of lead and the lowering of the sulfur content in gasoline have further improved the effectiveness of these devices.
- **Particulate traps:** Particulate traps collect soluble and carbonaceous particulate matter in the diesel exhaust and during regeneration convert it to CO_2 and water. Because sulfur in fuel can interfere with the operation of the device, the technology requires the use of ultra-low sulfur diesel.

GSE equipped with non-road engines are characteristically "open-loop" systems that have no combustion control feedback system to adjust the air/fuel mixture. For this reason, only the oxidation catalyst technology is used on these engines (both compression ignition and spark ignition).

In those applications where the non-road engines have been retrofitted with a "closed-loop" combustion control system, then the three-way catalytic converter can be used effectively to reduce emissions but limit the maximum power available for the GSE. Furthermore, because some types of GSE engines are tuned to run rich, adjusting the air/fuel ratio to run lean would limit the engine power available to the equipment.

Because these types of add-on control devices need to reach a critical temperature to allow the conversion of pollutants to take place, GSE with short duty cycles (i.e., low load factors) may not achieve the temperatures needed for maximum conversion efficiency. For particulate traps, backpressure increases as particulate matter collects on the trap. If the operating cycle of the GSE does not include sufficient periods of high load (which promotes the necessary regeneration temperature), it can affect the performance of the equipment. The ideal condition is a high-load activity level to regenerate the trap regularly and maintain low backpressure on the trap.

One other potential constraint of note is the space requirement for the add-on devices. Since such equipment has to be retrofitted onto GSE not originally designed to accommodate it, one must consider how the placement of the add-on device can be accomplished without interfering with the intended operation and maintenance of the GSE.

Evolving Engine Technology for Conventional Fuels

In the mid-1990s, the U.S. EPA began to issue non-road engine emission standards that are being phased in over a number of years; prior to these standards, non-road engines were essentially non-regulated. In particular, initial standards for non-road compression-ignition (e.g., diesel) engines were promulgated in 1996 and then more advanced standards were set in 2008. For non-road spark-ignition (e.g., gasoline) engines, the U.S. EPA promulgated standards to take effect over the period from 2004 through 2008. These standards will result in significant emission reductions (in some cases, greater than 90 percent) from the non-regulated baseline as the cleaner engines meeting the emission standards displace the uncontrolled equipment.

3.3.2 Alternative-Fuel GSE

Fuel-related solutions to reduce emissions from GSE include the use of alternative-fuel and electric-power GSE in place of conventional-fuel GSE, either through acquisition of new

purpose-built equipment or retrofitting of existing equipment. Today, a variety of alternative combustion fuels are available for use in internal combustion engines that power GSE.

The primary alternative fuels known to be used in GSE include compressed natural gas (CNG), liquefied petroleum gas (LPG, also known as propane), ethanol, and biodiesel. These fuels typically generate lower air emissions than the conventional fuels; however, the relative energy content and on-airport infrastructure requirements to provide alternative fuel may reduce the overall air quality benefit associated with the use of this equipment. In addition, accounting for off-airport electric power generation impacts associated with charging electric GSE also reduces the air quality benefits of this equipment. The detailed discussion of benefits and challenges of alternative-fuel GSE are presented in Section 3.4 (Economic and Environmental Challenges and Considerations with Alternative-Fuel GSE).

3.3.3 Operations/Maintenance-Related Approaches

Operators of GSE have developed specific operations and maintenance (O&M) programs for the GSE that they own. These procedures have been developed to reduce the overall cost of running GSE as well as to avoid operating delays associated with equipment breakdowns. However, there are potential air quality benefits to these O&M measures too, for example, (1) idling time restrictions and (2) maintenance activities.

Idling Time Restrictions Above and Beyond Regulatory Requirements

Most GSE duty cycles consist of short periods of high-load operation followed by extended periods of idle or engine off. Over a long period of operation, the engine load factor (ratio of actual work performed to the maximum work that the engine is designed to do) can account for differing operating conditions and must be taken into account when estimating emissions. Although load factors for GSE have been developed, they may be highly uncertain on a generalized basis when attempting to account for differences across multiple units of the same type, across airlines, and across airports. Equipment idle time can vary considerably and, in extreme cases where idle periods represent the major portion of the duty cycle, the load factor approaches zero while the actual emission rate per unit work performed approaches infinity.

Idling of GSE is a common practice, particularly for diesel equipment, primarily as a convenience to the operator to maintain the equipment in a ready mode and avoid lengthy warm-up periods in cold climates. However, an engine at idle continues to emit pollutants, although at a different rate from that under higher load conditions. Imposing idling restrictions on GSE (e.g., no idling longer than five minutes) could result in substantial emission reductions in the long term. Implementing such restrictions may be as simple as training operators to turn off the engine after use. Alternatively, an anti-idling device could be installed that automatically shuts off the engine after a pre-set period of time. For engines that need to be maintained in a "warm standby" condition for ready access or in the case where an equipment cab needs its interior temperature maintained for operator comfort, a small auxiliary unit can be integrated with the anti-idling device to keep the equipment in a ready condition while reducing overall emissions. Including the small auxiliary unit into such a system design would clearly limit the degree of emission reductions achieved in practice.

Maintenance Activities

In general, maintenance activities have been developed to cost effectively limit equipment downtime in maintenance while avoiding inconvenient equipment breakdowns during operations. As part of the field surveys, maintenance activities that have potential air emissions were noted along with any available mitigation options.

3.3.4 Other Approaches

At least two other approaches to managing GSE emissions also exist: emission-related fees and tenant lease agreements.

Emissions Fees

While no data were obtained indicating that GSE are being assessed emission fees at airports in the United States, several European airports assess fees on aircraft emissions.

Tenant Lease Agreements

Several airports have begun attempting to incorporate emission reduction goals into tenant lease agreements. However, the use of such goals in lease agreements can be problematic and may not be a viable option because the goals may not be legally binding on an airline.

There are numerous constraints on U.S. airport proprietors that would limit their ability to reduce emissions associated with airport operations. These constraints include federal laws preempting certain actions by airport proprietors to regulate air carriers, the ban on passenger head taxes, the prohibition against diverting airport revenue for non-airport purposes, and the requirement to impose only reasonable and not unjustly discriminatory terms and conditions on aeronautical users. (Reimer and Putnam, 2007)

3.3.5 Airport-Specific GSE Emission Reduction Measures

Presently, there are a great number and variety of GSE emission reduction measures in place (or planned) at airports of nearly every size and function located across the United States and internationally. The sponsors of these initiatives also range widely and include airlines, airport operators, and GSE providers.

Table 3-5 provides a partial sampling of these GSE emission reduction measures implemented over the past few years. For the purposes of this research project, this listing is not intended to be inclusive but rather to provide some examples of these programs. The GSE tutorial includes a more comprehensive and up-to-date compilation of these measures and programs.

This information pertains only to airside GSE and does not include the large number and wide array of other emission reduction and alternative-fuel programs at these airports.

3.4 Economic and Environmental Challenges and Considerations with Alternative-Fuel GSE

Prepared in support of Task 3, this section reports on the primary economic and environmental considerations and challenges associated with owning and operating GSE. Because this topic is multifaceted and comprehensive, the economic elements are discussed first and the discussion of the environmental factors follows.

3.4.1 Economic Considerations and Challenges

Compared to using traditional petroleum-based gasoline and diesel fuels, using alternative fuels (i.e., substitutes for traditional liquid, oil-derived motor vehicle fuels) in airport GSE may reduce energy costs, maintenance costs, and dependence on fossil fuels. The following material compares the costs of fueling GSE with conventional, petroleum-based fuels versus alternative fuels. In addition to fuel costs, characteristics such as performance, energy content, cold weather limitations, maintenance costs, and funding opportunities are also presented.

Table 3-5. Sampling of GSE emission reduction measures implemented by airports.

Implementer	GSE Program Details
Example Airport Programs	
Atlanta Hartsfield-Jackson International Airport (ATL)	At ATL, a new baggage system, extensive use of fueling carts in lieu of fueling trucks, and more than 200 new electric GSE units are expected to result in reductions in conventional fuel use and emissions associated with GSE. Virtually all of ATL's gates are equipped with preconditioned air and 400 Hz power, which greatly reduces the emissions that result from APU usage at the airport's gates (See also Delta Air Lines).
Boston Logan International Airport (BOS)	Delta Air Lines received a $3 million loan from Massport in 2009 for the purchase of 50 electric baggage cart tugs, 25 electric baggage conveyor belt vehicles, and charging stations as part of the replacement of Terminal A. Massport has a number of other GSE emission reduction programs under way at BOS.
Charlotte Douglas International Airport (CLT)	CLT introduced 10 battery-powered tugs on the Express ramps to replace their old diesel-engine counterparts, reducing N_2O emissions by as much as 70 tons.
Dallas-Fort Worth International Airport (DFW)	DFW selected Clean Energy Fuels in 2010 to construct and operate a new CNG refueling station at this airport. Most of the airport's fleet of more than 500 maintenance vehicles operates using CNG. The fleet is also fueled at another on-site CNG refueling station constructed in 2000.
Denver International Airport (DIA)	The Alternative-Fuel Vehicles (AFV) program was implemented with the construction of DIA. The GSE fleet at the airport includes 40 CNG bag tugs, nine electric bag loaders, and four electric cargo tractors. The CNG fleet at DIA is one of the largest in the country. The underground tunnel system connecting the terminal and concourses allows only CNG and electric vehicles. CNG pumping stations are available on site.
Detroit Metropolitan Wayne County Airport (DTW)	In 2007, DTW received a $1.4 million VALE grant for gate power and preconditioned air for 26 gates at the new North Terminal.
George Bush Intercontinental Airport (Houston) (IAH)	In 2008, IAH was awarded a $25,000 VALE grant for two new electric GSE units. This is only one of several GSE emission reduction programs undertaken by the Houston Airport System (HAS) and airlines that utilize the HAS airports.
Indianapolis International Airport (IND)	In 2008, Aircraft Service International Group (ASIG) purchased seven solar-powered hydrant carts for use at IND. (Notably, ASIG also operates these same carts at Seattle-Tacoma International Airport and Fort Lauderdale International Airport.)
John Wayne Airport (SNA)	In 2009, SNA's Airport Terminal Services added eTug electric tow tractors to its fleet and an eCart battery baggage cart. The eCart enables the eTug to operate 24 hours/day without the need for a stationary charge period. ETug also operates on its own set of batteries. This potentially reduces the number of tractors required because none have to be down for any period to charge.
Lambert-St. Louis International Airport (STL)	STL has approximately 400 vehicles and other GSE operating on biodiesel fuel including trucks, sweepers, plows, loaders, aircraft rescue and firefighting (ARFF) vehicles, and emergency generators. Currently STL is converting its remaining gasoline vehicles to CNG and its on-site CNG fueling station serves 60 airport maintenance vehicles.
Lehigh Valley International Airport (ABE)	In 2010, ABE received a $700,000 VALE grant for the purchase of eight preconditioned air units and eight electric GSE, the installation of three electric GSE rechargers, and the purchase of six new hybrid vehicles to replace older, conventional-fuel vehicles. The project is expected to save over 65,000 gallons of fuel and at an initially estimated cost savings of approximately $165,000 annually.
Los Angeles International Airport (LAX)	In 2011, eight airlines at LAX signed a joint agreement for the purchase and use of renewable synthetic diesel fuel for their GSE at this airport. The signees include ASIG (purchasing the fuel, transportation and dispensation of synthetic diesel), Rentech, Inc. (producer of RenDiesel fuel using a biomass gasification process at a facility in Rialto, CA), Alaska Airlines, American Airlines, Continental Airlines, Delta Air Lines, Southwest Airlines, United Airlines, United Parcel Service (UPS), and US Airways. In 2010, Los Angeles World Airports also drafted a GSE conversion policy requiring that all GSE be converted to zero-emission equipment by 2015.

(continued on next page)

Table 3-5. (Continued).

Implementer	GSE Program Details
Louisville International Airport (SDF)	In 2009, the airport's largest tenant United Parcel Service (UPS) was selected by the U.S. EPA to receive a $500,000 award to reduce diesel PM. The grant funds the replacement of 92 GSE cargo tugs and the extension of ground power electricity to parked aircraft, replacing 26 mobile diesel ground power units.
New York LaGuardia Airport (LGA)	At LGA, in 2006 Delta Air Lines replaced diesel GSE with fast-charging electric GSE, reducing emissions by 19.2 tons per year.
Norman Y. Mineta San Jose International Airport (SJC)	In 2009, SJC was awarded a $4.6 million VALE grant to install preconditioned air and electrical power upgrades at 13 gates in Terminal A, reducing diesel GSE use and aircraft engine operations.
Oakland International Airport (OAK)	As part of the Terminal 2 extension project at OAK, electric power for GSE was installed at each of the seven new gates. Southwest Airlines will begin using electric baggage loaders and is installing rapid battery chargers.
Philadelphia International Airport (PHL)	In 2009, PHL was awarded a $3 million VALE grant for the installation of preconditioned air at 24 gates, and 25 rechargers to support 184 electric GSE vehicles purchased by US Airways. The preconditioned air units at the US Airways gates are expected to reduce NOx emissions by 414.7 tons over the next 26 years. The 184 electric GSE vehicles will replace diesel GSE vehicles and are expected to reduce NOx by 191.9 tons over the next 13 years. Of note, this is only one of several VALE grants awarded at PHL over the past few years that were applied to the reduction of GSE emissions.
Phoenix Sky Harbor Airport (PHX)	As part of the City of Phoenix's alternative/clean fuel program, approximately 250 operational vehicles at PHX (including GSE) use low-sulfur fuel or other alternative fuels (i.e., CNG or biodiesel) or are hybrid vehicles.
Portland International Airport (PDX)	Since 1997, PDX has been replacing airport vehicles fueled by gasoline and diesel with vehicles fueled by CNG. PDX has 46 dedicated CNG vehicles including trucks and forklifts used as GSE. PDX also has several propane forklifts and a scrubber/sweeper as well as a fleet of 27 biodiesel pieces of off-road equipment.
Sacramento International Airport (SMF)	SMF instituted a program to deploy 54 alternative-fuel vehicles including 20 belt loaders converted from gasoline to electric power. The program saved the airlines that owned the vehicles $10,000 per vehicle.
Salt Lake City International Airport (SLC)	SLC has instituted a clean-fuel program composed of CNG, electric, biodiesel, and hybrid vehicles; CNG refueling stations; and economic incentives for tenants to convert to these technologies.
San Francisco International Airport (SFO)	The airport used an Inherently Low-Emission Airport Vehicle Program grant to purchase alternative-fuel vehicles and infrastructure including 54 electric vehicles such as bag tugs, belt loaders, and pushback tractors. The program also included the gasoline-to-propane conversion of 83 vehicles and the purchase of recharging systems for electric vehicles.
Seattle-Tacoma International Airport (SEA)	In 2010, SEA obtained $5 million from the Puget Sound Clean Cities Coalition to subsidize the purchase of 200 electric GSE vehicles and charging stations. The electric GSE will include bag tugs, belt loaders, and pushback tractors owned and operated by tenant airlines. The project initiates SEA's efforts to be the first airport in the United States to fully electrify its GSE fleet. SEA is also developing a plan to own the GSE and lease it for use to a consortium of airlines, thereby allowing for a more centralized approach to recharging. For APUs, SEA is anticipating a $22 million VALE grant for installing preconditioned air at each terminal area gate.
Westchester County Airport (HPN)	HPN was awarded a $1 million VALE grant for the replacement of gasoline and diesel GSE and the purchase of 25 electric GSE vehicles and 13 mini-chargers. The new GSE includes baggage and aircraft tractors, water trucks, and baggage belt loaders, reducing emissions by 330 tons per year and saving an estimated $240,000 annually in fuel costs.
	Example Airline Programs
Alaska Airlines	Alaska Airlines has converted or replaced a portion of its gas-powered fleet with cleaner-burning propane units or hybrid GSE. Approximately 10 percent of the GSE fleet has been converted to electric.
American Airlines	Since 2000, American has converted approximately 30 percent of its GSE bag tractors and belt loaders from gasoline and diesel to electric. American has also installed fast electric chargers at DFW, New York JFK, Chicago O'Hare (ORD), and LAX for its GSE.

Table 3-5. (Continued).

Implementer	GSE Program Details
Continental Airlines	Continental reports that NOx emissions from GSE have been reduced by approximately 75 percent at IAH by switching to electric GSE and other emission reduction technologies.
Delta Air Lines	In 2010, Delta opened its new GSE facility at ATL where it conducts the majority of the GSE fuel conversions. Delta has also announced plans to purchase approximately 600 new GSE units valued at $50 million including approximately 100 electric GSE units for airports that have the infrastructure to support electric.
Horizon Air	As of January 1, 2010, over 65 percent of the GSE fleet is electric.
Southwest Airlines	As of March 2012, Southwest has purchased or converted more than 850 GSE units to electric including baggage tugs, belt loaders, lavatory trucks, carts, and pushback tractors. In doing so, the carrier reduced its GSE fuel consumption by approximately 700,000 gallons annually. Additionally, Southwest has converted to gate service electricity in 61 of the 64 airports it serves, reducing APU fuel consumption by more than 15 million gallons in 2007.
US Airways	As of the end of 2010, more than 20 percent of the US Airways GSE fleet was electric, including 38 electric tugs recently added in Philadelphia in conjunction with the Philadelphia Division of Aviation. US Airways has also committed to purchase 1.5 million gallons per year of synthetic diesel fuel for use in GSE at LAX.
United Airlines	United Airlines operates about 325 electric vehicles at DIA ranging from baggage tractors and forklifts to golf carts and also operates approximately 200 natural gas vehicles including tugs, vans, and light-duty pickup trucks.
United Parcel Service	At the UPS WorldPort facility at SDF, electric loaders have been installed at each loading dock along with 400 Hz GPUs. UPS has also re-powered 92 tugs with cleaner gasoline engines through an EPA grant. At LAX, UPS is also re-powering more than 100 tugs to use newer low-emission engines. UPS is one of eight airlines at LAX that signed an agreement for the use of synthetic renewable diesel fuel beginning in 2012. UPS has more than 2,200 tugs throughout the world and plans to re-power all of them.
Example GSE Provider Programs	
Aviapartner	Based in Brussels, Aviapartner operates 31 GSE units throughout Europe and is using a new "Visualizer" airport system in order to facilitate more efficient use of its vehicles, thereby reducing fuel use and emissions. It is also assessing the concept of "pooling" GSE for common use among airlines.
Elite Line Services	Elite Line Services has converted all of Alaska Airlines' cargo operation to electric forklifts and fast charge. In addition, it is in the middle of a project to upgrade all the Anchorage International Airport (ANC) cargo forklift fleet to electric.
FRAPORT	The operator of the Frankfurt Airport is conducting trials on hydrogen-powered GSE as well as conducting GSE use studies to improve the efficiency of GSE utilization with the objective of reducing fuel use and emissions.
Menzies Aviation	Menzies Aviation has implemented electric baggage tugs at its locations and recently added 11 eTugs to its GSE fleet. As of May 2009, 30 tugs out of 110 in its fleet were electric.
Rentech Inc.	Rentech has entered into agreements with several airlines in the Los Angeles Basin to use its alternative fuel in GSE. Major airline partners include American, Southwest, Delta, United, and Continental.
SwissPort	A leading international ground services and cargo handling provider, SwissPort follows a strict renewal and replacement strategy for its GSE all over the world. Electric bag and cargo tractors are employed in many locations and, where not, they will be introduced over the next few years. SwissPort also works closely with major GSE manufacturers in developing modern vehicles with low fuel consumption and low emissions. All its diesel vehicles have been outfitted with filters for soot particles.

Types of Alternative Fuel

The Energy Policy Act of 1992 (EPAct) defines an alternative fuel as a fuel that is substantially non-petroleum and yields energy security and environmental benefits. Congress passed the EPAct to reduce U.S. reliance on foreign oil by providing tax breaks and requirements for the use of alternative fuels (Sections 501 and 507) to fuel federal fleets. The EPAct considers the following fuels to be alternative options to conventional gasoline or diesel fuel:

- Mixtures containing 85 percent or greater ethanol (E85)
- Mixtures containing 20 percent or greater biodiesel meeting ASTM D 6751
- Natural gas (compressed or liquefied)
- Liquefied petroleum gas (propane)
- Methanol
- Hydrogen
- Electricity

To focus the evaluation of transitioning from GSE using traditional petroleum-based gasoline or diesel fuels to GSE using alternative fuels, the following paragraphs describe each alternative fuel previously listed, with the exception of methanol.

However, not all the alternative fuels listed under the EPAct of 1992 are available for widespread use in GSE. Availability, especially for biofuels and hydrogen, is particularly limited based on airport location. Moreover, methanol is not often used in the aviation industry because of its lack of widespread availability. Other limiting characteristics of methanol include its corrosive nature, low energy density (about 50 percent less than gasoline), and poor performance below 45 degrees Fahrenheit. Therefore, although methanol may be used as a component to produce biofuels and has chemical and physical characteristics similar to ethanol, it is not discussed further.

Ethanol. Ethyl alcohol, or ethanol, is a clear, colorless liquid made from fermenting a biomass in carbohydrates. Starch- or sugar-based ethanol sources include corn grain and sugar cane; cellulose-based sources include grass, wood, and crop residues.

Low-level blends of ethanol and gasoline (less than 10 percent ethanol) can be used in any gasoline-powered engine without modification, although blends of less than 85 percent ethanol and 15 percent gasoline (E85) do not qualify as an alternative fuel under the 1992 EPAct. Typically, E85 is priced lower than gasoline on a gallon-for-gallon basis but more than gasoline on an energy-equivalency basis. Blends containing more than 10 percent ethanol are only approved for use in flexible fuel vehicles (FFVs), which are capable of running on both E85 and gasoline. The characteristics of ethanol follow:

- ***Availability.*** There are about 200 ethanol production plants located in the United States, primarily in the Midwest. As of August 2010, approximately 8 million FFVs were on U.S. roads (although only a portion of these vehicles actually use ethanol); there were 53 different 2011 FFV models from domestic and foreign automakers.
- ***Energy balance and high octane.*** Despite some misconceptions, the total amount of energy used to produce ethanol (i.e., by farming, shipping, and production equipment) is less than the energy released when it is burned (known as the energy balance). The energy balance for corn-based ethanol is approximately 1.24 (for 1 unit of energy produced, 1.24 units of energy are released) and it is expected to increase as technology advances.

  As a high-octane fuel, ethanol increases horsepower, helps prevent pre-ignition or engine knocking, and enables engines to operate at a higher compression ratio. In the United States, ethanol is often added to gasoline in a low-level blend to oxygenate the fuel and reduce air pollution emissions.

- ***Cold temperature fuel gelling.*** Because E85 may freeze in lower temperatures, fueling stations may need to switch to a lower blend of ethanol during winter months to prevent starting problems. All FFVs can transition to E70 or other lower-level blends without any adjustments.
- ***Energy efficiency.*** Ethanol produces less energy per gallon than gasoline, depending on the blending ratio. As the ratio of ethanol to gasoline increases, the fuel economy decreases. E85 generates 15 to 30 percent lower gas mileage because E85 has approximately 27 to 36 percent less energy content per gallon than gasoline.
- ***Engine modifications.*** Ethanol is a strong cleaning agent and has the ability to degrade engine parts manufactured from materials such as natural rubber, plastics, and even metals over time. Therefore, E85 should not be used in existing gasoline or diesel engines without performing modifications. Many existing petroleum-based gasoline-powered vehicles can be converted to use E85 through kits approved by the U.S. EPA. A typical conversion kit mounts in a vehicle's engine compartment and continuously monitors engine and emission controls. The kit supplies supplementary fuel injection to allow for the same ethanol/gasoline compatibility as a FFV. Conversion kit costs vary by the engine type and vehicle model.
- ***Storage.*** Ethanol has a shelf life of about 3 months although it can last for several years if it is properly sealed. The ethanol content in E10 can absorb more water than gasoline, and when the water evaporates valuable fuel components are lost, reducing the efficiency of the fuel. A vehicle's fuel should be used or replaced within 2 to 3 weeks, or even sooner in humid conditions.

Biodiesel. Biodiesel is produced by vegetable oil, animal fat, or cooking grease reacting with alcohol (typically methanol) in the presence of a catalyst. In the United States, common sources for biodiesel production are soybean oil and recycled cooking oil. B100 consists of 100 percent pure or "neat" biodiesel and contains no petroleum-based diesel. A blend must be at least 20 percent biodiesel and 80 percent petroleum diesel (B20) to be considered an alternative fuel under the EPAct.

To be considered fuel-grade biodiesel, B20 must satisfy the performance requirements and the defined physical and chemical properties of the American Society for Testing and Materials (ASTM) outlined in Specification D 7467. B20 meets the EPAct requirements, minimizes the limitations of high-level blends, and is the most common blend in the U.S.; therefore, this section primarily focuses on the key considerations of B20.

The characteristics of biodiesel follow:

- ***Availability.*** A total of 613 biodiesel fueling stations (288 public and 325 private of various blends) were located in the United States as of January 2011. The U.S. DOE estimates that the United States has enough soy oil, feedstock, and recycled restaurant grease to provide 1.7 billion gallons of biodiesel per year (approximately 5 percent of on-road diesel use).
- ***Cold temperature fuel gelling.*** Low-temperature gelling of biodiesel clogs fuel filters and makes the fuel unusable. B20 may begin to gel when the temperature reaches approximately 8 degrees Fahrenheit, depending on the feedstock used to produce it.

  For example, biodiesel produced from canola, safflower, and sunflower oils are less likely to gel in cold temperatures while coconut and palm oils (high in saturated fat) are more likely to freeze. Therefore, operators should know what feedstock was used to produce the biodiesel prior to use in cold weather. The National Renewable Energy Laboratory and the U.S. DOE do not recommend the use of high-level blends such as B100 due to concerns about cold temperature gelling (at around 32 degrees Fahrenheit), material compatibility, maintenance requirements, and solvency properties. Appling additives to the fuel such as kerosene, using filter and block heaters, and/or storing vehicles indoors may help reduce the likelihood of cold temperature gelling.

- ***Energy content.*** Similar to ethanol, as the proportion of biodiesel to petroleum-based diesel fuel increases, the energy content decreases. Biodiesel (B100) has a 7 to 9 percent lower energy content than petroleum-based diesel fuel, which reduces an engine's fuel economy, peak horsepower, and peak torque. These changes, especially in blends greater than B20, may offset fuel cost savings.
- ***Maintenance.*** Switching from petroleum-based diesel to biodiesel may clog fuel filters because of biodiesel's solvency characteristics. Existing sediment from petroleum-based diesel could be dislodged with the start of biodiesel use (especially higher blends), reducing fuel flow to the engine and causing a stall. If the sediment causes the filter to rupture, sediment could travel into the fuel lines, pump, and injectors, resulting in expensive repairs. Therefore, during the initial transition from petroleum-based diesel to biodiesel (especially blends of B20 or higher), routine maintenance should be performed to check for and replace clogged fuel filters.

  Biodiesel blends higher than B20 have a higher viscosity and density than petroleum-based diesel, which may cause unburned fuel to bypass the piston rings and drain into the oil pan. This may cause the accumulation of engine sludge, shortening the engine's lifespan and requiring more frequent engine oil and filter changes.
- ***Shelf life.*** Compared to petroleum-based diesel, stored biodiesel is more likely to react with oxygen and form a gel-like substance; this is a concern when using GSE that is only operated occasionally or when storing GSE for more than 6 months after the manufacture date. The higher the concentration of biodiesel in the blend, the faster it is likely to degrade. Using storage-enhancing additives and/or a dry, semi-sealed, cool container can also alleviate storage concerns.

  Biodiesel is an active growing environment for microorganisms because it is a greater attractant of water than petroleum-based diesel. If biodiesel is stored for long periods of time, the denser water will collect at the bottom of the fuel tank and promote microbial growth that may cause engine failure, fuel filter clogging, and corrosion.
- ***Solvency.*** Because biodiesel is a natural solvent, high concentrations of biodiesel will soften and degrade rubber compounds that may be located in fuel hoses, gaskets, and fuel pump seals. B20 can be used in most diesel vehicles and fuel-injection equipment manufactured after 1993 without having an impact on operating performance or requiring engine modifications. The U.S. DOE has not received any reported rubber compound problems due to B20 (i.e., ruptured fuel hoses or fuel pumps) since 2006, even with older engines. However, a thorough search for incompatible rubber compounds in the fueling system should be performed prior to fueling GSE with biodiesel.

Compressed Natural Gas. Commonly used to heat stoves and houses, CNG is pressurized natural gas that remains colorless, odorless, and noncorrosive. CNG primarily consists of methane drawn from gas wells, oil wells, and coal bed methane wells, although it may also consist of synthetic gas, landfill gas, and coal-derived gas in smaller quantities. Although vehicles can use natural gas as either a liquid or a gas, most vehicles use the gaseous form compressed in high-pressure fuel cylinders at 3,000 to 3,600 pounds per square inch.

The characteristics of CNG are as follows:

- ***Availability.*** CNG is typically imported through pipelines although it may also be transported as a cryogenic (super-cold) liquid. An extensive network of natural gas pipelines is presently located across the United States, connecting wellheads and electrical generation plants to residential, commercial, and industrial buildings for heating and cooling. Natural gas accounts for about one-fourth of the energy used in the United States, although only one-tenth of 1 percent is currently used for transportation fuel.
- ***Performance and operating costs.*** No noticeable difference in horsepower, acceleration, and cruise speed exists between a CNG vehicle and a similarly sized gasoline or diesel vehicle. The

cost of CNG is typically 15 to 40 percent less than gasoline or diesel and the CNG market has historically been more stable.

- ***Maintenance.*** Oil changes in a CNG vehicle are less frequent compared to a gasoline or diesel vehicle, because CNG burns cleaner, producing fewer oil deposits.
- ***Storage requirements.*** CNG only contains about a quarter of the energy by volume of gasoline. Therefore, the driving range of a CNG vehicle is less than that of comparable gasoline and diesel vehicles, requiring more frequent fueling. Larger storage tanks can be installed to increase range, but the additional weight displaces payload capacity. Furthermore, the higher cost of the fuel cylinders and CNG tanks means that CNG vehicles cost from $3,500 to $6,000 more than their gasoline-powered counterparts.

Operating temperature during refueling must be kept below negative 40 degrees Fahrenheit to reduce liner stress. To reduce risk, all CNG tanks should have a residual pressure control system.

Propane or Liquefied Petroleum Gas. LPG is a naturally forming gas composed of both petroleum and natural gas. LPG comes from either petroleum refining (45 percent of LPG used in the United States) or natural gas processing (55 percent). Because of its versatility and efficiency, LPG is commonly used for heating and cooking in rural areas of the United States that are not connected to natural gas pipelines.

LPG vehicles operate similarly to gasoline vehicles with SI engines. LPG changes to a liquid state in an LPG vehicle's fuel tank, where it is stored at a pressure of about 300 pounds per square inch. Today, most propane vehicles are conversions from gasoline vehicles.

The characteristics of LPG are as follows:

- ***Availability.*** Propane has been used as a commercial motor fuel for over 80 years. As of 2011, there are more than 270,000 on-road LPG vehicles in the United States and more than 10 million worldwide. Many are used in fleets, including light- and heavy-duty trucks, buses, taxicabs, police cars, and rental and delivery vehicles.
- ***Maintenance.*** LPG has an octane rating from 104 to 112 compared with 87 to 92 for conventional gasoline fuel. The higher octane rating increases power output and fuel efficiency while preventing engine knocking. Propane's low carbon and oil contamination characteristics have resulted in documented engine life of up to two times that of gasoline engines. No cold temperature problems are associated with LPG since the fuel mixture (propane and air) is completely gaseous. Propane operating costs for fleet vehicles range from 5 to 30 percent less than that for conventional or reformulated gasoline vehicles.
- ***Performance.*** Since LPG is less dense than gasoline, power may decrease, but operators rarely notice this loss. LPG fleet operators have reported that horsepower and torque capabilities, as well as vehicle cruising speed, are roughly comparable to those for gasoline vehicles. Fuel economy on new engines is also comparable to that of gasoline engines.
- ***Refueling.*** LPG vehicles have a refueling rate of approximately 10 to 12 gallons per minute, which is comparable to that of gasoline; and presently approximately 10,000 refueling stations are located across the country.
- ***Dedicated LPG vehicles.*** The availability of dedicated LPG vehicles has declined. No LPG passenger cars or trucks have been produced commercially in the United States since 2004. However, certified installers can retrofit vehicles to run on propane. Since the LPG is stored in high-pressure fuel tanks, separate fuel systems are required for bi-fuel vehicles that run on both LPG and conventional fuels. Propane conversions for light duty vehicles from gasoline to dedicated propane cost roughly between $4,000 and $12,000.
- ***Energy content.*** LPG has about 25 percent less energy than a gallon of gasoline, increasing fuel consumption and reducing range. As with CNG vehicles, larger storage tanks can be installed to increase range, but the additional weight will displace payload capacity.

Electric Vehicles. Electric vehicles (EVs) are powered exclusively by an electric motor. Most EVs operate with electricity that is stored in a battery that must be recharged by plugging into a suitable outlet. Batteries are also recharged by regenerative braking, a method of storing the kinetic energy from braking into elastic potential energy that can be redistributed and used to power the car. Whenever an EV is not accelerating, the vehicle's momentum can be used to generate electricity. EVs can run on either alternating current (AC) or direct current (DC) power. Unlike vehicles powered by fossil fuels, EVs can also receive their power from nuclear power, solar power, tidal power, wind power, or other sources.

The characteristics of electric vehicles are as follows:

- ***Availability.*** Presently, approximately 10 percent of the 72,000 GSE units currently in use in the United States are electric. Thus, more GSE units are electric than any other alternative fuel type.
- ***Operational costs.*** Compared to the volatile cost of fossil fuels, the price of electricity is much more stable. The fuel cost of driving an EV is normally less than that for a gasoline or diesel vehicle, although actual cost depends on the cost of electricity per kilowatt-hour and the energy efficiency of the vehicle. Estimating that electricity costs 13 cents per kilowatt-hour, the fuel for an EV with an energy efficiency of 3 miles per kilowatt-hour costs about 4 cents per mile. This translates to only $1 per gallon if 25 miles per "gallon" is assumed. EV charging rates may also vary by time of use (peak vs. non-peak) and season.

  As an example, the Metropolitan Airports Commission purchased a flat-bed two-seater Cushman Motors e-Ride exv2 electric utility vehicle for $22,265 to be used by parking management staff. The utility vehicle contains a 72-volt AC motor with a driving range of 45 to 55 miles per charge. At Minneapolis-St. Paul International Airport (MSP), the EV can be powered for a cost of approximately $202 per year. Comparatively, MSP pays approximately $818 per year to fuel a Ford Escape Hybrid and $1,653 to fuel a Ford F-150 pickup truck.

  Some EV manufacturers include warranties to cover batteries for approximately 80,000 to 100,000 miles. Since the battery is expensive to replace, operators should consult with the dealer prior to purchasing an EV to come to a clear consensus on the expected battery life and warranty.
- ***Energy efficiency.*** An EV can convert approximately 75 percent of the chemical energy stored in the batteries to power the wheels while an internal combustion engine (ICE) can only convert about 20 percent of the energy stored in gasoline. In stop-and-go operations, EVs are even more efficient, since electricity is not consumed while the vehicle is stopped (no idling).
- ***Performance.*** The acceleration, speed, and handling of an EV can equal or exceed that of conventional ICE vehicles. EV operation is also much quieter than ICE vehicles. However, EV's have limited towing ability over longer distances and thus cannot be used for some operations (e.g., towing an aircraft from a gate to a maintenance hangar). EVs may also have difficulty hauling larger loads up inclined ramps.
- ***Maintenance.*** EVs require less maintenance than ICE vehicles. No oil changes, belts, spark plugs, fuel injectors, or emissions tests are involved. The completely sealed cooling systems do not require refilling, replacement, or flushing. EVs also have fewer moving parts, which results in reduced inventories, lower operating capital, and fewer spare parts. Regenerative braking also reduces wear and tear on brake pads.
- ***Conversions.*** The cost of converting a gasoline-powered vehicle to an EV can be high although it could potentially be offset by lower operational and maintenance costs. Converting a GSE powered by an ICE to electric power requires completely removing the engine and adding a battery pack, cabling, electric motor, and metering equipment. Therefore, converting to electric power is most cost effective when the vehicle's engine has reached the end of its life cycle or needs to undergo expensive repairs. Instead of purchasing a new ICE, converting to electric power could be considered.

Converting to electric power does not require certification from the U.S. EPA. However, vehicles that have a gross vehicle weight rating of less than 10,000 pounds, use more than 48 volts of electricity, and have a maximum speed greater than 25 miles per hour must meet Federal Motor Vehicle Safety Standard 305: Electrolyte Spillage and Electrical Shock Prevention.

- ***Range anxiety.*** EVs have a limited battery storage capacity that must be replenished by plugging the EV into an electrical power source. Neighborhood electric vehicles (NEVs), commonly found at airports, are limited to operating on roads with speed limits of 35 miles per hour. However, since NEVs are limited to speeds of 35 miles per hour, NEVs are not considered light-duty vehicles and are not eligible for fleet credit under the EPAct of 1992. Battery packs are also heavy, take up considerable vehicle space, are expensive, and may need to be replaced over the life cycle of the EV.
- ***Charging stations.*** The National Electrical Code (NEC) has established three distinct plug-in electric vehicle (PEV) charging station levels. Each NEC level describes the amount of power that can be supplied to the vehicle to be charged (the more power delivered, the faster the charge). The three NEC levels are defined in Table 3-6.

  NEC Level II charging is the EV industry standard. The Society of Automotive Engineers (SAE) has approved a standard plug known as SAE J1772.

  The cost to provide recharging outlets at existing parking sites can be expensive. The cost for a Level II station, which includes engineering, permitting, hardware, weather-proofing, and service costs, is approximately $10,000 per outlet for the first two new outlets; for more than two outlets, the costs would drop to approximately $2,000 per outlet. Installation of recharging stations at surface parking lots is typically more expensive, because trenching is typically required.

  At some airports, GSE may be able to share power with the electric motor used to power the jetway for passenger boarding since it is only used a few minutes per hour. The electrical circuit may be able to support charging stations when the jetway motor is not being used. The circuit can also reduce installation costs since wire and conduit runs are shorter.

  Other factors to consider prior to installing an EV charging station include airport layout, regulations, and traffic patterns to and from charging stations.
- ***Recharge time.*** Fully recharging an EV may take from 4 to 8 hours, although fast-charging stations can be purchased to limit recharging times. However, even a "quick charge" to 80 percent capacity can take over 15 minutes. If conveniently located, GSE can be plugged into recharging stations overnight or during break periods/downtime (by recharging EVs overnight operators may be able to take advantage of off-peak rates to decrease the cost of powering EVs).

Hydrogen. The simplest and most abundant element in the universe, hydrogen can be produced from fossil fuels, biomass and other renewable energy sources, or by electrolyzing water.

Table 3-6. National Electrical Code plug-in electric vehicle charging levels.

Charging Level	Voltage (VAC)	Current (AMPS)	Power (kVA)	Input Phase	Standard Outlet	Estimated Full Charge Time
Level I	120	12	1.44	Single	NEMA 5-15R (Standard 110v outlet for U.S.)	8-14 hours
Level II	208/240	32	6.7/7.7	Single	SAE J1772/3	4-8 hours
Level III	480	400	192	Three	No standard. Some adopting Tokyo Electric Power Company	< 1 hour

Source: Thomason (2009).

Hydrogen vehicles either convert the chemical energy of hydrogen into torque by combustion or electrochemical conversion in a fuel cell. Similar to ICE vehicles that combust gasoline or diesel fuel, hydrogen vehicles with ICEs burn hydrogen in the engine to produce energy that powers the vehicle. In a fuel cell, hydrogen reacts with oxygen to produce electricity that powers an electric traction motor.

The characteristics of hydrogen are as follows:

- ***Energy content.*** At 52,000 BTU per pound, hydrogen has the highest energy content per unit weight of any known fuel; this is approximately three times the energy of a pound of gasoline. Therefore, the process of converting hydrogen to energy using engines or fuel cells is much more efficient than the comparable gasoline counterparts.
- ***Availability.*** No fuel-cell vehicles powered with hydrogen are available yet for sale. Hydrogen is available only as an industrial or scientific chemical product, not as a bulk fuel. No bulk hydrogen distribution infrastructure exists near the scale of that for fossil fuels. Transporting hydrogen is also difficult since it must be refrigerated to maintain a liquid state.
- ***Distribution.*** Generating hydrogen, transporting it via truck or pipeline, and storing it aboard the vehicle may be an inefficient and expensive process. Similar to CNG, hydrogen typically requires heavy tanks or insulating bottles if stored as a super-cold liquid.
- ***Lifespan.*** Hydrogen fuel cells have less than half of the lifespan of a traditional ICE vehicle (about 1,900 hours or 57,000 miles).
- ***Storage requirements.*** The amount of energy contained in 1 gallon of gasoline is equivalent to the amount of energy stored in 2.2 pounds of hydrogen gas; thus, a light-duty fuel-cell vehicle must store from 11 to 29 pounds of hydrogen to drive 300 miles or more. Storing this much hydrogen on a vehicle would require more space than the trunk size of a typical car.

  Since hydrogen technology is still in its infancy, expensive, and not readily available, using hydrogen in GSE was not evaluated further.

Hybrid Electric Vehicles. In a hybrid electric vehicle (HEV), a small ICE is connected to an electric generator. Electric power is combined with gasoline, diesel, or an alternative fuel to power the electric traction motors, which in turn power the wheels of the vehicle. The drive is electric (battery powered) at low speeds and powered by the main ICE at high speeds.

The EPAct of 1992 did not originally consider HEVs as alternative-fuel vehicles. However, the National Defense Authorization Act for Fiscal Year 2008 amended the 1992 EPAct to include four new categories of vehicles as "alternative-fueled vehicles" under Section 30B of the Internal Revenue Service Code, including "a new qualified hybrid motor vehicle."

The characteristics of HEVs are as follows:

- ***Range/gas mileage.*** Unlike in EVs, the batteries in HEVs do not need to be plugged in to recharge. HEVs also avoid the inconvenience of long charging times and the cost of charging infrastructure. Some HEVs can be driven up to 70 miles on a single gallon of gasoline. The electric motor provides additional power to assist the engine in accelerating, passing, or hill climbing, allowing for a smaller, more efficient ICE to be used. In some HEVs, the electric motor solely provides power for low-speed driving conditions where ICEs are least efficient. HEVs usually cost 5 to 7 cents per mile to operate while conventional ICE vehicles cost 10 to 15 cents per mile.

  To prevent wasted energy from idling, HEVs automatically shut off the engine when the vehicle comes to a stop and restart it as soon as the accelerator is pressed. Like in EVs, regenerative braking systems in HEVs capture deceleration energy and convert it to electricity to propel the vehicle and increase overall efficiency.
- ***Maintenance.*** HEVs must undergo the same maintenance procedures as conventional vehicles although spare parts may be more difficult to find and have a higher cost.

Cost of Conventional Fuels vs. Alternative Fuels

This subsection compares the cost of conventional petroleum-based fuels with the cost of alternative fuels, including the historical, current, and forecast costs. Alternative fuels are typically not subject to dramatic price fluctuations because they are less dependent on the price of crude oil (unlike petroleum fuel prices). However, depending on the type of alternative fuel and/or the percentage blend, some alternative fuels still fluctuate based on crude oil prices, national security, spikes in the cost of agricultural products, and other factors.

Historical Cost. Figure 3-1 depicts the 11-year average cost of gasoline and diesel fuels compared to alternative fuels from 2000 to 2011 per gallon of gasoline equivalent (a discussion of the gallon of gasoline equivalent values is provided in the subsection Fuel Operating Cost Considerations). The cost fluctuations of gasoline and ultra-low sulfur diesel (ULSD) fuel prices compared to alternative fuels from January 2008 to October 2011 are shown in Table 3-7.

Current Cost. The national average cost per gallon for gasoline, diesel, and alternative fuels in January 2012 is provided in Table 3-8. As shown, CNG had the lowest cost per gallon at $1.24 less than gasoline (on an energy-equivalent basis); E85 was 23 cents less per gallon than gasoline; and propane cost 29 cents less per gallon than gasoline. Compared to the cost of diesel, B20 prices were 9 cents higher and pure biodiesel (B100) prices were 34 cents higher per gallon.

According to the U.S. Energy Information Administration, the world average gasoline and diesel fuel prices are predicted to increase from $2.35 and $2.44 per gallon, respectively, in 2009 to $3.69 and $3.89 per gallon, respectively, in 2035 (in 2009 dollars). Annual average diesel prices are anticipated to be higher than gasoline prices because of increased demand for diesel. With the estimated increases in the cost of gasoline and diesel fuels, alternative fuels are expected to become more affordable. For example, in 2022, the retail price of gasoline is anticipated to be $3.43 per gallon while the price of E85 is anticipated to be $2.68 on a gallon of gasoline equivalent (GGE) basis. (The following paragraphs discuss the gasoline equivalent basis.)

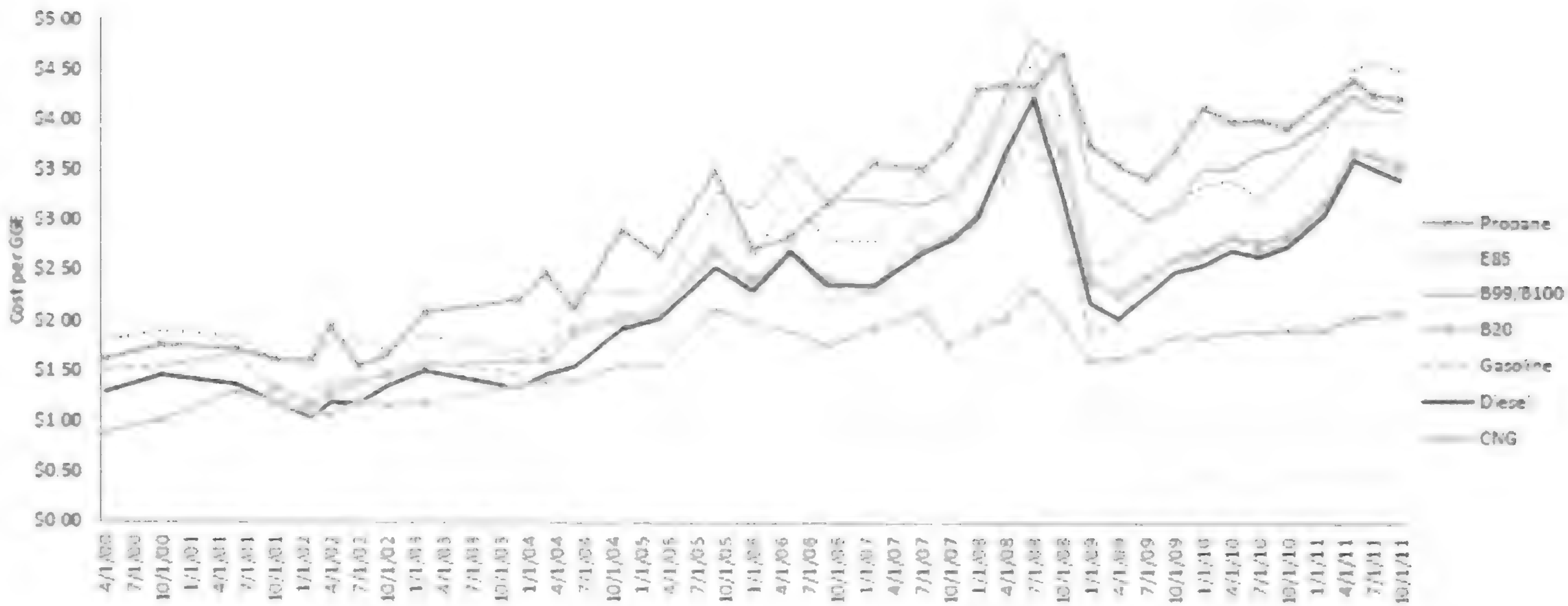
Fuel Operating Cost Considerations

When viewed separately from other operational cost factors, the cost per gallon of a fuel may be misleading. The energy content and location/availability of an alternative fuel, which are described below, should also be factored in to provide a more accurate estimate of fuel cost.

Energy Content. Because of differing energy content per gallon for fuels, the price paid per unit of energy content differs from the price paid per gallon. Prices for the alternative fuels in terms of cost per GGE are generally higher than their cost per gallon because of their lower energy content. For example, 1.41 gallons of E85 are required to do the same work as 1 gallon of diesel fuel. Therefore, although E85 was priced at $3.14 per gallon compared to that of gasoline at $3.37 in January 2012, the cost for E85 is actually more expensive than gasoline on a GGE basis ($4.44 per gallon). Table 3-9 lists conversion factors that should be used to achieve a level playing field as either GGE or gallon of diesel equivalent (GDE).

Taking these conversion factors into account, Table 3-10 lists the average fuel price of alternative fuels in GGE and GDE from January 2008 to January 2012. Prices for all fuel types peaked in July 2008 and declined through January 2009. From January 2009 to April 2011, fuel prices have all increased, as illustrated in Figure 3-2.

Location/Availability. The price of an alternative fuel is dependent upon where the fuel is manufactured and blended and where fueling infrastructure is located. For example, while gasoline and diesel consumption is highest along America's coasts, most ethanol plants are concentrated in the Midwest where it is absorbed in local and regional markets.



GGE = gallon of gasoline equivalent

Source: U.S. Department of Energy (2012b).

Some figures in this report have been converted from color to grayscale for printing. The electronic version of the report (posted on the web at www.trb.org) retains the color versions.

Figure 3-1. U.S. 11-year average fuel prices in cost per gallon of gasoline equivalent.

Table 3-7. Average U.S. fuel prices.

National Average Cost Per Gallon	2008				2009				2010				2011			
	Jan	Apr	Jul	Oct	Jan	Apr	Jul	Oct	Jan	Apr	Jul	Oct	Jan	Apr	Jul	Oct
Gasoline	$2.99	$3.43	$3.91	$3.04	$1.86	$2.02	$2.44	$2.64	$2.65	$2.84	$2.71	$2.78	$3.08	$3.69	$3.68	$3.46
Diesel	$3.40	$4.14	$4.71	$3.65	$2.44	$2.27	$2.54	$2.79	$2.87	$3.02	$2.95	$3.07	$3.45	$3.62	$3.95	$3.81
Compressed natural gas[a]	$1.93	$2.04	$2.34	$2.01	$1.63	$1.64	$1.73	$1.86	$1.85	$1.90	$1.91	$1.93	$1.93	$2.06	$2.07	$2.09
Ethanol (E85)	$2.51	$2.87	$3.27	$2.82	$1.81	$1.88	$2.13	$2.27	$2.38	$2.42	$2.30	$2.44	$2.75	$4.52	$3.26	$3.19
Propane	$3.12	$3.15	$3.14	$3.38	$2.73	$2.58	$2.48	$2.69	$2.99	$2.89	$2.90	$2.85	$3.05	$4.41	$3.09	$3.06
Biodiesel (B20)	$3.37	$3.98	$4.66	$4.04	$2.67	$2.49	$2.69	$2.88	$2.96	$3.12	$3.06	$3.14	$3.50	$3.69	$4.02	$3.91
Biodiesel (B100)	$3.69	$4.31	$4.88	$4.64	$3.47	$3.27	$3.08	$3.19	$3.59	$3.57	$3.75	$3.82	$4.05	$4.26	$4.19	$4.18

[a]Compressed natural gas is measured on an energy-equivalent basis (gallon of gasoline equivalent).

Source: Data from U.S. Department of Energy, Energy Efficiency and Renewable Energy. "Clean Cities Alternative Fuel Price Report," Clean Cities, January 2008 - January 2012, www.afdc.energy.gov/afdc/price_report.html (accessed April 11, 2012).

Table 3-8. Average cost per gallon of fuel.

National Average Cost Per Gallon	January 2012
Gasoline	$3.37
Diesel	$3.86
Compressed natural gas[a]	$2.13
Ethanol (E85)	$3.14
Propane	$3.08
Biodiesel (B20)	$3.95
Biodiesel (B100)	$4.20

[a] Compressed natural gas is measured on an energy-equivalent basis (gallon of gasoline equivalent).
Source: U.S. Department of Energy (2012a).

Table 3-11 identifies how alternative-fuel prices for the month of January 2012 varied based on U.S. region. As shown, the location of each fuel pump relative to the production facility and customer base is an important factor to consider when estimating fuel price. For example, the cost of B100 varied by as much as $1.42 per gallon between the Gulf Coast region ($3.50) and the Central Atlantic region ($4.92).

Price also varies depending on whether the purchaser of alternative fuel buys in bulk supply from the producer via rail, pipeline, or barge (spot price); a limited supply from a refueling truck (rack price); or at a traditional pump (retail price). Furthermore, the retail price is also influenced by whether the fueling station is branded or unbranded and the degree of competition in the vicinity of the station.

Biofuels are not often shipped via pipeline so they are generally blended at the local wholesale terminal. Not all fueling stations sell high percentage biofuel (ethanol and biodiesel) blends such as E85 or B100. Biofuel prices are contingent upon seasonal availability; factors involved in growing, processing, and distributing biofuels can contribute to price fluctuations. The use of low-level biofuel blends such as E10 and B5 can be influenced by local air quality regulations or federal and state renewable fuel standards. Additionally, as more alternative-fuel producers and suppliers enter the market, competition will likely increase the available supply of biofuels, potentially lowering the price of biofuels.

Other Fuel Cost Considerations. Federal, state, and local tax provisions may be applicable for certain fuels used for off-highway business use. Fuel cost adjustments may include taxes or tax credits such as excise taxes, alcohol fuel credits, biofuel tax credits, gasoline tax refunds, etc.

Table 3-9. Energy content equivalency factors.

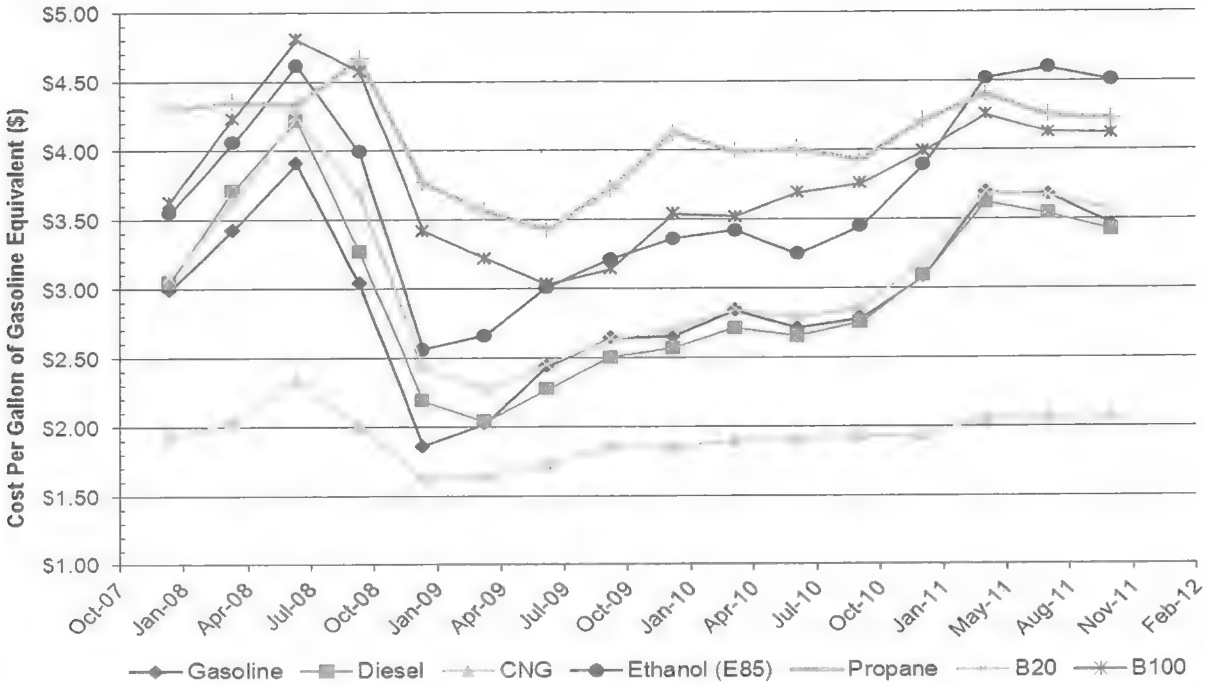
Fuel	Lower Heating Value	Conversion Factor to Dollars per Gallon of Gasoline Equivalent	Conversion Factor to Dollars per Gallon of Diesel Equivalent
Gasoline	115,400 BTU/gal	1.00	–
Diesel	128,700 BTU/gal	–	1.00
Compressed natural gas	960 BTU/ft^3	1.00	1.12
Ethanol (E85)	75,670 BTU/gal	1.41	1.58
Propane	83,500 BTU/gal	1.38	1.54
Biodiesel (B20)	–	0.91	1.02
Biodiesel (B100)	117,093 BTU/gal	0.99	1.10

Source: U.S. Department of Energy (2012a).

Table 3-10. Average U.S. fuel prices in gallon of gasoline and diesel equivalence.

Fuel	2008				2009				2010				2011				2012
	Jan	Apr	Jul	Oct	Jan	Apr	Jul	Oct	Jan	Apr	Jul	Oct	Jan	Apr	Jul	Oct	Jan
Cost per Gallon of Gasoline Equivalent																	
Gasoline	$2.99	$3.43	$3.91	$3.04	$1.86	$2.02	$2.44	$2.64	$2.65	$2.84	$2.71	$2.78	$3.08	$3.69	$3.68	$3.46	$3.37
Diesel	$3.05	$3.71	$4.22	$3.27	$2.19	$2.04	$2.27	$2.50	$2.57	$2.71	$2.65	$2.75	$3.09	$3.62	$3.54	$3.42	$3.46
Compressed natural gas	$1.93	$2.04	$2.34	$2.01	$1.63	$1.64	$1.73	$1.86	$1.85	$1.90	$1.91	$1.93	$1.93	$2.06	$2.07	$2.09	$2.13
Ethanol (E85)	$3.55	$4.06	$4.62	$3.99	$2.56	$2.66	$3.01	$3.21	$3.36	$3.42	$3.25	$3.45	$3.89	$4.52	$4.60	$4.51	$4.44
Propane	$4.31	$4.36	$4.34	$4.67	$3.77	$3.56	$3.43	$3.72	$4.13	$3.99	$4.01	$3.93	$4.22	$4.41	$4.26	$4.23	$4.26
Biodiesel (B20)	$3.08	$3.63	$4.25	$3.69	$2.43	$2.27	$2.45	$2.63	$2.70	$2.85	$2.79	$2.86	$3.19	$3.69	$3.67	$3.57	$3.61
Biodiesel (B100)	$3.63	$4.24	$4.81	$4.58	$3.42	$3.22	$3.03	$3.14	$3.54	$3.52	$3.69	$3.76	$3.99	$4.26	$4.13	$4.12	$4.14
Cost per Gallon of Diesel Equivalent																	
Gasoline	$3.33	$3.82	$4.36	$3.39	$2.08	$2.26	$2.72	$2.95	$2.96	$3.17	$3.03	$3.10	$3.43	$4.12	$4.10	$3.85	$3.76
Diesel	$3.40	$4.14	$4.71	$3.65	$2.44	$2.27	$2.54	$2.79	$2.87	$3.02	$2.95	$3.07	$3.45	$4.04	$3.95	$3.81	$3.86
Compressed natural gas	$2.15	$2.27	$2.61	$2.24	$1.82	$1.83	$1.93	$2.08	$2.07	$2.12	$2.13	$2.15	$2.15	$2.30	$2.30	$2.33	$2.38
Ethanol (E85)	$3.96	$4.53	$5.15	$4.44	$2.86	$2.96	$3.36	$3.58	$3.75	$3.81	$3.63	$3.84	$4.33	$5.04	$5.14	$5.02	$4.96
Propane	$4.80	$4.86	$4.84	$5.21	$4.21	$3.97	$3.82	$4.15	$4.61	$4.45	$4.01	$4.39	$4.70	$4.92	$4.76	$4.71	$4.75
Biodiesel (B20)	$3.32	$4.05	$4.74	$4.11	$2.71	$2.53	$2.74	$2.93	$3.02	$3.18	$3.11	$3.19	$3.56	$4.12	$4.09	$3.98	$4.02
Biodiesel (B100)	$4.05	$4.73	$5.36	$5.10	$3.82	$3.59	$3.38	$3.50	$3.95	$3.92	$4.12	$4.19	$4.45	$4.75	$4.60	$4.59	$4.61

Source: Data from U.S. Department of Energy, Energy Efficiency and Renewable Energy. "Clean Cities Alternative Fuel Price Report," Clean Cities, January 2008 - January 2012, www.afdc.energy.gov/afdc/price_report.html (accessed April 11, 2012).



Source: U.S. Department of Energy, Energy Efficiency and Renewable Energy. "Clean Cities Alternative Fuel Price Report," Clean Cities, January 2008 - January 2012, www.afdc.energy.gov/afdc/price_report.html (accessed April 11, 2012).

Figure 3-2. Average nationwide (U.S.) fuel prices in cost per gallon of gasoline equivalent.

Additionally, bulk fuel purchase discounts or in the case of electric vehicles, off-peak electrical charging usage should be considered in the overall fuel costs for each GSE fuel type.

Non-Fuel Cost Considerations

Beyond the costs for purchasing the fuel, there are indirect costs that should also be considered when evaluating alternative-fuel GSE.

Labor. Labor costs represent the single largest expense of the total cost of owning and operating GSE. As shown in Table 3-12, ramp labor represents over 80 percent of the total

Table 3-11. Regional variance in alternative-fuel prices in January 2012.

	Average Cost Per Gallon							
Fuel	New England	Central Atlantic	Lower Atlantic	Mid-west	Gulf Coast	Rocky Mountain	West Cost	National Average
Gasoline	$3.60	$3.46	$3.46	$3.29	$3.15	$3.09	$3.68	$3.37
Diesel	$4.05	$3.83	$3.82	$3.74	$3.77	$3.77	$4.15	$3.86
Compressed natural gas[1]	$2.42	$2.28	$1.69	$1.84	$1.89	$1.69	$2.38	$2.13
Ethanol (E85)	$3.76	$3.23	$3.23	$3.06	$3.05	$2.99	$3.35	$3.14
Propane	$3.37	$2.84	$3.17	$2.98	$2.89	$2.97	$3.36	$3.08
Biodiesel (B20)	$3.96	$4.07	$3.89	$3.71	$3.91	$3.93	$4.13	$3.95
Biodiesel (B100)	$3.73	$4.92	$3.83	$4.16	$3.50	$4.32	$4.16	$4.20

[1] Compressed natural gas is measured on an energy-equivalent basis (gallon of gasoline equivalent).
Source: Data from U.S. Department of Energy, Energy Efficiency and Renewable Energy. "Clean Cities Alternative Fuel Price Report," Clean Cities, January 2012, www.afdc.energy.gov/afdc/price_report.html (accessed April 11, 2012).

Table 3-12. Example of baggage tractor (gasoline/diesel) maintenance cost considerations.

Cost Type	Per Tractor	Total (25 Tractors)	Costs per Tractor: Annual	Percentage of Total Annual	Annual Non-labor	Percentage of Total Annual Non-labor
Ownership Costs						
Initial Cost	$25,000	$625,000				
Average Life (years)	20		$1,250	1.2%	$1,250	10.8%
GSE Storage Facility (capital costs)[a] ($ per 20-year period)		$100,000				
Average Storage Costs ($ per tractor)			$200	0.2%	$200	1.7%
Residual Resale Value[b]	$2,500	$62,500	-$125	-0.1%	-$125	-1.1%
Total Ownership Costs Per Year			**$1,325**		**$1,325**	
Operating Costs						
Utilization/day (hours)	8	200				
Utilization/year (hours)	2,920	73,000				
Lifetime Utilization (hours)	58,400	1,460,000				
Maintenance (annual hours)	100	2,500				
Maintenance (lifetime hours)	2,000	50,000				
Maintenance Labor Rate ($40 per hour)			$4,000	3.9%		
Maintenance Parts			$2,000	1.9%	$2,000	17.2%
Annual Training Costs			$1,000	1.0%	$1,000	8.6%
Ramp Labor ($30 per hour)			$87,600	84.9%		
Fuel Burn per Hour ($2.50 per gallon @ 1 gallon per hour)			$7,300	7.1%	$7,300	62.8%
Total Operating Costs Per Year			**$101,900**		**$10,300**	
TOTAL ANNUAL COSTS			***$103,225***	***100.0%***	***$11,625***	***100.0%***
Average Cost per Hour of GSE Utilization			$35.35			

[a] Assume storage capital expenditure for GSE facility with 20-year life.
[b] Depreciation, tax deductions, and cost of capital not considered.

cost to own and operate baggage tractors. Alternative-fuel equipment should be evaluated to determine if their operation could reduce labor costs and/or free up labor resources for other non-fuel emissions-related ground handling operations. Alternative-fuel equipment should be evaluated for the potential to reduce the time to adequately train the operator and/or improve operational learning curves and efficiencies while reducing safety-related incidents and accidents.

Other labor cost reduction strategies include the adjustment to the work schedule. The labor schedule for the ground servicing of aircraft is derived by the aircraft schedule. Where it may not be possible for an airline to support point-to-point passenger service, the hub-and-spoke schedule enables the airlines, especially large "legacy" carriers, to support a vast system network. Aircraft arrive from the spoke stations to the hub station in a scheduled arrival bank. Passengers arriving at the hub station then connect to a closely timed departure bank resulting in the shortest overall travel time for the connecting passenger. While this schedule is preferable to the passenger, a "peaked" hub-and-spoke schedule places the greatest demand on GSE and associated labor resources and increases the potential for airline arrival and departure delays and resultant aircraft fuel expenditures and emissions.

Alternatively, "de-peaking" the schedule places less demand on labor and equipment resources. In a de-peaked schedule, arriving and departing aircraft are scheduled more uniformly throughout the day; thus, fewer resources are required for any given hour in the schedule compared to that of a peaked schedule.

For example, consider a simplified 16-aircraft operation at an airport (eight arrivals and eight departures per day): a peaked schedule could consist of four departures at 8:00 a.m., four arrivals at 12:00 noon, four departures at 4:00 p.m., and four arrivals at 8:00 p.m.; a uniformly distributed schedule could have one departure at 8:00 a.m., an arrival at 9:00 a.m., and alternating arrivals and departures each hour throughout the day. While the GSE fuel cost and GSE emissions may be identical in each of these cases for any given GSE type, the variable labor and GSE inventory requirements for the peaked schedule could be as much as four times that of the de-peaked schedule in this example. It should be noted, however, that in the de-peaked schedule, the average passenger connect times may be expected to increase, which may result in the loss of market share to airline competitors, depending on the alternatives that were available to the passenger. It is the airline passenger that creates the demand for air travel, the demand that the travel occur during certain times of the day, and the demand that layovers between connecting flights be limited. To de-peak air travel may require re-regulation and subsequent restructuring of the airline industry.

Other Non-Fuel Cost Considerations. Federal, state, and local tax provisions may be applicable for certain vehicles used in off-highway-related businesses. In addition to the purchase price of equipment, net adjustments should include tax credits such as credits for the purchase of alternative-fuel vehicles. Other tax-related considerations would include the applicability of business-related Section 179 depreciation expense for GSE. Other cost considerations include GSE insurance coverage for damage, liability, and business interruption loss, cost of capital (funding costs to purchase GSE), and administration overhead.

Cost of Alternative-Fuel GSE

The cost of an alternative-fuel GSE vehicle varies heavily based on several airport-specific factors such as the type of GSE, quantity of GSE purchased (i.e., bulk rates), existing contracts with the airport, the manufacturer, performance capabilities, custom features, lighting and signage, etc. Alternative-fuel GSE, particularly electric, LPG, and CNG vehicles, normally have a higher up-front cost than gasoline or diesel GSE. In some cases, low-level blends of ethanol and biodiesel may be useable in existing vehicles without modifications (although additional maintenance is required and caution should be taken during the transitioning process). On average, the initial cost of electric GSE can be 30 to 35 percent more expensive than gasoline GSE. Similarly, the higher cost of the fuel cylinders and tanks means that light-duty CNG and LPG vehicles cost from $3,500 to $6,000 more than their gasoline-powered counterparts.

Life-cycle costs, which incorporate fuel cost savings, maintenance costs, vehicle lifespan, and infrastructure, must also be considered or else it would not make financial sense to convert to electric, LPG, or CNG with existing technology. Cost savings are usually realized when considering life-cycle cost benefits. Additionally, non-cost factors, such as the benefits from improved air quality, GSE performance, and airport marketing and public image, should also be considered.

Maintenance Costs

When considering total operating costs, the GSE airport administrator must also consider maintenance costs, which include not only maintenance materials and supplies, but also the hourly rates for mechanics' wages. The GSE administrator should ensure that all GSE propulsion systems are warranted by the original equipment manufacturer to operate on alternative fuels; however, converted propulsion systems are typically not included under the vehicle warranty. As a representative example (for consideration purposes only), Table 3-12 shows how the mainte-

nance cost (labor and parts) of a typical gasoline or diesel baggage tractor can amount to a large percentage of the total life-cycle cost.

Biofuel GSE. Because biofuels (ethanol and biodiesel) are natural solvents, they may degrade rubber compounds found in fuel hoses, gaskets, and fuel pump seals (especially higher blends); this degradation could result in clogged filters, increasing maintenance costs compared to conventional fuels (although engines manufactured after 1993 typically do not experience problems). If the filter ruptures, sediment could travel into the fuel lines, pump, and injectors, causing expensive repair needs. Also, since biofuels are greater attractants of water than petroleum-based fuels, they promote microbial growth in fuel tanks. Microbial growth may cause engine failure, fuel filter clogging, and corrosion. Therefore, if GSE uses ethanol or biodiesel, routine maintenance should be performed to check for and replace clogged fuel filters. The GSE administrator should prepare for increased engine fuel filter and fuel storage filter replacements and maintain equipment inventories accordingly. Prior to fueling GSE with high blends of biofuels, precautions should be taken to verify that no incompatible rubber compounds are in the fueling system.

Maintenance personnel should change the fuel filter following the use of the first tank of biofuels, and fuel filters at dispensing units should be changed when operators notice that the flow of fuel slows. Periodic fuel testing may also be required to ensure fuel quality. Similarly, maintenance personnel should periodically check for free water at the bottom of fuel storage tanks. If biofuels must be stored for over 6 months, additional maintenance and labor may be required to prevent and/or mitigate fuel contaminated by water (e.g., seasonal fuel tank draining).

To reduce the potential for cold temperature fuel gelling of biofuels, the GSE administrator may need to purchase additives such as kerosene, filter and block heaters, and/or indoor storage space, adding to the maintenance cost.

Electric GSE. EVs require no oil changes, belts, spark plugs, fuel injectors, or emissions testing; do not require refilling, replacement, or flushing of cooling systems; and have smaller engine part inventories. EVs (as well as HEVs) also reduce wear and tear on brake pads through regenerative braking, a process that converts kinetic energy from braking to electricity that is stored in the battery. Therefore, maintenance costs (parts and labor) are less than for GSE fueled with gasoline, diesel, or biofuels.

Comparing maintenance costs per hour of conventional fuel GSE to electric GSE is inaccurate since there is no idling time in an EV. Thus, when considering the maintenance cost per hour of a gasoline or diesel GSE to be equal to the cost per hour of an electric GSE, the electric GSE can accomplish 65 to 70 percent more work for the same amount of maintenance; if maintenance is scheduled by hours, a gas unit is maintained almost 2.5 times more often than an electric.

CNG and LPG GSE. The oil in a CNG vehicle does not need to be changed as frequently as a gasoline or diesel vehicle because CNG burns cleaner, producing fewer oil deposits. LPG has an octane rating from 104 to 112 (compared with 87 to 92 for conventional gasoline fuel), which helps prevent engine knocking. Because of LPG's low carbon and oil contamination characteristics, the engine life of a LPG vehicle can be up to two times that of gasoline engines. Unlike with biofuels, no cold temperature problems are associated with LPG since the fuel mixture is completely gaseous.

Training

Compared to conventional-fuel GSE, training costs for alternative-fuel GSE may be higher. Training may help GSE operators identify when GSE charging or alternative-fuel infrastructure is malfunctioning and when potential safety hazards exist. For example, since LPG and CNG are clear and odorless, GSE operators may need to be briefed on adding an odorant to the fuel mixture and identifying signs of leaks in fuel tanks.

Operators of electric GSE should also be informed of the charging time required, when the GSE needs to be recharged to ensure demand is met, and the best time to charge the vehicle if peak electrical usage rates apply. To reduce fuel consumption and maintenance costs, the GSE administrator may consider providing fuel-efficient driving and vehicle-operating training annually to GSE drivers, regardless of the fuel type. The training can help ensure that GSE are used as intended and that driving techniques are used that reduce fuel consumption, greenhouse gas emissions, and accident rates.

Cost of Infrastructure

New fueling infrastructure may be necessary to support a fleet of alternative-fuel GSE. In addition to costs, the space available to accommodate new fueling infrastructure must also be considered.

For example, electric charging infrastructure, LPG, or CNG fuel tanks may be required if no existing infrastructure nearby the airport is available. Although ethanol and biodiesel could be stored in existing gasoline and diesel infrastructure (after appropriate cleaning), supplementary fuel tanks would still be required unless the entire fleet is transitioned to run on biofuels.

CNG and LPG fueling stations have high installation costs; for example, since a CNG fueling facility requires dedicated supply lines, compression apparatus, storage cylinders, and special dispensers, the construction cost ranges from $400,000 to $600,000. The high cost also factors in the need for CNG and LPG fuel tanks to be designed to withstand high internal pressures and be resistant to accidental punctures.

Electric charging infrastructure can be expensive at an airport without sufficient existing electric power available. Although some electric GSE could be plugged into a traditional 120-volt outlet, the time to fully charge the vehicle could take over 8 hours. A Level II or Level III "quick charge" station is likely required to satisfy fleet demand during peak air travel periods. The cost of a charging station can be anywhere from $10,000 (Level II) to $60,000 (Level III) depending on existing electrical outlets, wiring, power demand, capacity, and the quantity purchased.

However, bridge electric power sharing or other opportunities may be available to extract power for charging without the need for additional infrastructure (or could reduce installation costs of new infrastructure). For instance, a jet bridge only uses the power that is supplied to it for about 5 percent of the day; the remaining 95 percent could be used for electric GSE charging.

Life-Cycle Cost Considerations

Since alternative-fuel GSE and supporting infrastructure typically have a higher initial cost than conventional-fuel GSE, airports with higher annual fuel consumption rates may have a quicker return on investment when purchasing alternative-fuel and/or electric GSE compared to lower fuel-use airports. The break-even fuel cost varies based on the type of GSE, the purchase price, available funding, required maintenance, type of fuel used, infrastructure costs, and other factors. For instance, using electric bag tractors, belt loaders, cargo loaders, lavatory service trucks, and narrow-body aircraft tractors reduces fuel, maintenance, and high spare-part and equipment costs.

As an example of life-cycle cost considerations, the cost-benefit analysis of electric GSE performed by Idaho National Laboratories is described in the following paragraphs.

Idaho National Laboratories GSE Cost-Benefit Analysis Study. In February 2007, Idaho National Laboratories performed a study to evaluate the costs associated with operating baggage tractors, belt loaders, and pushback tractors. A cost model was developed to assist airlines and other stakeholders in future evaluations of deploying GSE. The approach included visiting four airports and working with two airlines to obtain data on GSE capital, operating, maintenance, and infrastructure costs.

The study found that electric GSE has lower operating costs than ICE GSE for the baggage tractor, belt loader, and pushback tractor. Capital costs for new ICE GSE are significantly lower than for new electric GSE. The payback time for electric GSE ranges from 3 to 7 years when no cost-sharing is provided. With cost-sharing and/or grants, the payback time for electric GSE can be reduced to 3 years or less, with life-cycle cost savings accruing over the life of the GSE.

The study also showed that converting old ICE vehicles to electric or implementing group purchases can help lower the cost of electric GSE. Techniques such as utilizing existing bridge supply power and utilizing smart power-sharing charge systems to reduce supply requirements can be used to help lower infrastructure costs.

VALE Program Funding

As discussed previously, the FAA established the VALE Program in 2005 to help airport sponsors meet their obligations under the CAA and to assist regional efforts to meet the NAAQS. The program provides sponsors with financial and regulatory incentives to increase their investments in proven, commercially available low-emission technology.

Eligible alternative fuels under the VALE Program include fuels that are primarily non-petroleum based, are cleaner burning than conventional petroleum-based fuels, and lessen U.S. dependence on foreign oil. The VALE Program follows the definition of alternative fuels established by the U.S. EPA and the U.S. DOE as part of the EPAct. Hybrid vehicles that combine gasoline or diesel engines with an electric motor are also eligible. Eligible hybrids must substantially displace the vehicle's gasoline or diesel fuel use and meet the VALE Program's low-emission standards.

Vehicles and engines that are eligible for funding under the VALE Program must either be U.S. EPA certified (new vehicles) or U.S. EPA verified (retrofit technology). Infrastructure development funded under the VALE Program, such as the installation of EV charging stations, must be located on-airport. Airport sponsor ownership of equipment is required in most instances and generally preferred to ensure accountability and to avoid situations where tenants relocate or experience financial difficulties. Funding for alternative-fuel and EV charging stations is limited to demand that is directly related to eligible VALE activities, excluding other airport or facility electrification needs that otherwise may or may not be AIP or PFC eligible. No more than 10 percent of station capacity can be dedicated for public use.

All vehicles and equipment purchased or converted under VALE must be an integral part of the aeronautical, transportation, security, or maintenance services at the airport, used on a regular basis in normal operation of the airport, and stored and maintained within the airport boundary. Vehicles can only be used outside the airport boundary if such use is minor, intermittent, and related to its primary mission to deliver airport services at the airport.

As an example, 25 electric GSE units (three aircraft tow tractors, nine baggage tractors, five belt loaders, four stair trucks, and four lavatory/water trucks) and 13 recharging stations were purchased by the Westchester County Airport (New York) for $2.47 million in 2009. The GSE and charging stations were acquired with the assistance of a VALE grant of $1.1 million in addition to assistance from the New York State Department of Transportation.

3.4.2 Environmental Considerations and Challenges

This subsection identifies and describes the principal environmental factors associated with owning and operating GSE with an emphasis on the use of alternative fuels. Because air quality is the principal environmental consideration given to alternative-fuel GSE, air emissions are discussed first followed by the issues associated with water quality, noise, solid/hazardous wastes, etc.

Emission Reduction Potentials and Penalties

The fundamental physical and chemical properties of alternative fuels as they pertain to air emissions are presented in this section. Specifically, emissions of PM, NO_x, CO, hydrocarbons (HC), and, where applicable, HAP/air toxics (AT) and greenhouse gas (GHG) emissions are discussed. The emissions reduction potentials and penalties compared to conventional fuels (i.e., gasoline and diesel) are also discussed. (For consistency with other sections, the fuels are presented in alphabetical order.)

Biodiesel. Due to the production process, biodiesel is typically oxygenated (up to 10 percent) where conventional diesel contains no oxygen, which affects the engine combustion process. For example, researchers observed an increase in brake-specific fuel consumption (BSFC) of 18 percent when using biodiesel in a CI diesel engine when compared to conventional diesel fuel (Gumus 2010, Canakci 2007). These and other important physical and chemical properties of biodiesel are discussed further as they relate to air emissions.

Although biodiesel has been shown by a majority of studies to reduce emissions of CO, HC, and PM from levels produced by conventional diesel, emission reduction potentials largely depend on the biodiesel blend percentage as well as the source feedstock of the fuel (Fazal et al. 2011).

For example, measured CO emissions are generally reduced from conventional diesel levels due to the presence of oxygen in the biofuel (i.e., B100) and can range from between 9 and 17 percent using frying waste oils (Cheng et al. 2008, Utlu and Kocak 2008, Murillo et al. 2007), to between 18 and 33 percent using soybean (Canakci 2007, Haas et al. 2001, Qi et al. 2009) and rapeseed (Kegl 2008) oils, to 81 percent from mahua oil feedstock (Raheman and Ghadge 2007). Like CO, CO_2 emission reductions through the use of biodiesel are variable and depend on the percentage of the biodiesel blend as well as the feedstock by which it was produced (Utlu and Kocak 2008, Cheng et al. 2008). B100 produced from soybean oil has been shown to reduce HC emissions from levels emitted using conventional diesel fuels by 27 to 55 percent (Canakci 2007, Haas et al. 2001, Qi et al. 2009). HC reductions within this range have also been reported for rapeseed oil (Kegl 2008), and for frying waste oil (Cheng et al. 2008).

Concentrations of HAPs found within B100 yellow grease biodiesel, including those of acetaldehyde, acrolein, benzene, 1,3-butadiene, formaldehyde, and naphthalene, were shown to increase over levels documented in ULSD fuel; however, with the exception of 1,3-butadiene, none of the increased concentrations were considered to be statistically significant (Holden et al. 2006). PM emissions and smoke measurements from combustion of a variety of biodiesel blends show reductions of up to 53 percent over conventional diesel (Haas et al. 2001, Qi et al. 2009, Nabi et al. 2009).

As shown in Figure 3-3, adopting the use of biodiesel can greatly reduce emissions of pollutants such as CO, HC, and PM but may present penalties with respect to NO_x emissions. Some

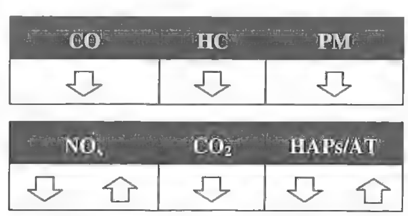


Figure 3-3. Emission reduction potential/penalty of biodiesel compared to conventional diesel.

studies on the effects of biodiesel on CI engine emissions have observed a reduction in NO_x emissions over that of conventional diesel fuel of up to 25 percent (Utlu and Kocak 2008, Qi et al. 2009, Aydin and Ilkilic 2010). However, other studies have demonstrated an increase in biodiesel-related NO_x emissions of up to 30 percent when compared to combustion emissions of conventional fuel engines (Nabi et al. 2009, Canakci 2007, Raheman and Ghadge 2007, Murillo et al. 2007).

Notably, NO_x increases resulting from biodiesel usage can be mitigated or offset with mechanical modifications to the engine or with fuel additives. For example, the U.S. Army tested B20 on U.S. Air Force GSE that was normally fueled with either regular diesel or JP-8 aviation fuel, and revealed that alteration of the injection timing as well as the installation of exhaust gas recirculation (EGR) systems lowered NO_x emissions by up to 10 percent when compared to conventional diesel fuel (Yost 2005). Researchers noted a 4 percent increase in NO_x over conventional diesel emissions when applying B100 produced from frying waste oil but were able to obtain reductions in NO_x of 6 and 8 percent when introducing methanol and fumigated methanol-based additives, respectively, to the B100 fuel. However, the researchers noted that the use of fumigated methanol additives increased the concentrations of NO_2 emitted from the engines (Cheng et al. 2008). Others created a dual-fuel mix of biodiesel and biogas to achieve significant NO_x emission reductions over ULSD, when tests on the biodiesel component alone performed worse than ULSD, suggesting that biogas mixing is another means to compensate for the potential for elevated biodiesel NO_x emissions (Yoon and Lee 2011).

Compressed Natural Gas. Lower fuel density and higher octane levels relative to gasoline allow CNG to be combusted at higher compression ratios and higher temperatures within SI engines (Das et al. 2000), which affects fuel consumption and pollutant characteristics of the fuel (Aslam et al. 2006).

Gasoline SI engines retrofitted to burn CNG typically reduce the level of CO by up to 80 percent of that produced by burning gasoline (Jahirul et al. 2010, Aslam et al. 2006) and effect reductions in CO_2 on the order of 30 percent (Zarante and Sodre 2009). HC emissions can be reduced between 30 and 50 percent, depending on engine throttle conditions (Aslam et al. 2006, Jahirul et al. 2010).

It has also been observed that, although the nonmethane component of HC emissions can be greatly reduced from that of gasoline, methane (CH_4) emissions tend to increase due to the abundance of CH_4 in the fuel (Korakianitis et al. 2011). High levels of CH_4 in the exhaust of CNG-fueled vehicles also provide a mechanism for the production of increased levels of HAPs (i.e., formaldehyde and acetaldehyde) when compared to gasoline-fueled vehicles (Correa and Arbilla 2005); however, these levels are still lower than those measured for diesel fuel (Turrio-Baldassarri et al. 2006).

NO_x emissions from the use of CNG can be elevated when compared to emissions from gasoline use by as much as 41 percent (Jahirul et al. 2010). However, studies have observed 170 percent higher NO_x levels in SI engines when compared to gasoline, and lower levels when compared to diesel fuel in dual-fueled CI engines (Korakianitis et al. 2011). Modifications of CI engine injection timing can reduce CNG-related NO_x emissions and are often a function of the pilot fuel used to initiate combustion in the case of dual-fueled vehicles (Carlucci et al. 2008). Blending hydrogen (H_2) with CNG causes NO_x emissions to increase substantially at higher loads, even though the practice can further reduce carbon-related emissions (Bysveen 2007).

Emissions of fine (i.e., $PM_{2.5}$) and respirable (i.e., PM_{10}) fractions of PM associated with CNG have been found to be greatly reduced from that of traditional diesel fuel; however, PM emissions of smaller size ranges were comparable to that of traditional diesel, suggesting that CNG emits similar amounts of ultrafine particulates to traditional diesel fuel (Ristovski et al. 2000a). Gasoline SI engines converted to accept CNG fuel show variable results with respect to PM,

whereby CNG usage offered PM reductions with respect to some operating loads and speeds and increases with respect to others (Ristovski et al. 2000b, Ristovski et al. 2004).

Notably, data from the U.S. EPA suggest that replacing diesel GSE with CNG equivalents, including aircraft pushback tractors, baggage tugs, loaders, carts, forklifts, ground power units and service trucks, can increase HC emissions anywhere between 5 and 215 percent, where replacing gasoline GSE of the same type can effect HC reductions of anywhere between 65 and 98 percent. CO emissions can decrease by between 20 and 55 percent by replacing gasoline GSE with CNG GSE but can increase by between 4,000 and 5,000 percent when compared to diesel-powered equivalents.

Although many studies indicate NO_x increases when using CNG rather than gasoline equipment, the U.S. EPA only reports increases (135 percent) with respect to some two-stroke gasoline equipment, and otherwise claims that an approximate 25 percent reduction in NO_x is possible by converting gasoline equipment to CNG. When compared to diesel GSE, CNG GSE typically decreases NO_x emissions between 55 and 80 percent depending on the type of equipment. Reductions of PM emissions by using CNG GSE are approximately 98 percent relative to diesel GSE, and reductions relative to gasoline GSE are variable and range between 15 and 98 percent. Finally, CO_2 reductions made possible by replacing diesel and gasoline GSE with CNG equivalents range from 10 percent to up to 45 percent, respectively (U.S. EPA 1998).

Liquefied Petroleum Gas. LPG consists of a mixture of propane and/or butane gases (and their chemical derivatives), which exhibit specific gravity two to three times lower than that of diesel fuel (Saleh 2008). LPG can cause decreased vehicle power output due to increased fuel displacement and lower thermal efficiency over that of conventional gasoline (Ceviz and Yuksel 2006), leading to potentially increased fuel consumption and some emissions.

The U.S. EPA has documented HC reductions from replacing gasoline GSE (including aircraft pushback tractors, tugs, loaders, carts, forklifts, ground power units, and service trucks) with LPG-fueled equivalents of between 45 and 60 percent for four-stroke SI engines and up to 97 percent for two-stroke engines. However, emissions of HC from LPG equipment increased by up to 155 percent when compared to diesel vehicles. CO reductions in the same study were approximately 40 to 55 percent relative to four-stroke gasoline GSE and 20 percent relative to two-stroke GSE. CO emissions from LPG increased in upwards of 5,000 percent when compared to diesel-powered equivalents.

With respect to NO_x, LPG usage creates a reduction of up to 25 percent relative to four-stroke gasoline equipment and up to 80 percent relative to diesel-powered equipment. Emissions of PM for GSE using LPG decreased by as much as 98 percent relative to both two-stroke gasoline and diesel GSE, but decreased by only 15 to 35 percent when compared against four-stroke gasoline SI GSE. Lastly, CO_2 emissions from LPG GSE compared to gasoline and diesel GSE were found to be variable, sometimes increasing by up to 15 percent for some equipment and decreasing by up to 40 percent for others (U.S. EPA 1998).

A study confirmed the U.S. EPA's findings of lowered PM emissions from LPG vehicles compared to gasoline vehicles but also noted that particle sizes increased slightly over those measured from gasoline exhaust. The same study also concluded that CO_2 emissions produced from LPG combustion effected a 15 percent decrease relative to gasoline equivalents but only found statistically significant results with respect to higher operating speeds (Ristovski et al. 2005). Saleh (2008) also expanded upon some of the U.S. EPA's findings by uncovering that LPG reductions of NO_x and CO relative to diesel fuel were highest when the engine was operating at low load and when the LPG blend consisted of at least 30 percent butane. The research also indicated that application of EGR on LPG engines can further reduce observed emission reductions (Saleh 2008).

Another study determined that LPG vehicles emit significantly more mercury (Hg) than conventional-fuel equivalents (Won et al. 2007). A similar elemental analysis of LPG exhaust also concluded that levels of manganese (Mn), vanadium (V), arsenic (As), and selenium (Se) are higher in LPG exhaust than in gasoline exhaust, regardless of operating speed (McKenzie et al. 2006). Further, air toxic species of fluorene, anthracene, and benzo(b)fluoranthrene were found to be elevated in LPG exhaust over that of gasoline exhaust at low engine power settings, while species fluoranthrene, pyrene, benzo(b)fluoranthrene, indeno(1,2,3-cd)pyrene, and dibenzo(a,h)anthracene were elevated over that of gasoline exhaust levels at high engine power settings (McKenzie et al. 2007).

Electricity. Electric vehicles are classified as either pure battery electric vehicles, fuel cell electric vehicles, or hybrid electric vehicles. Electricity-powered vehicles are considered environmentally friendly because they do not typically produce direct exhaust-related air emissions. However, because electricity demand may increase due to the use of these vehicles, the source of electricity generation must be considered when evaluating the potential emissions savings.

The air emission considerations for battery electric vehicles are discussed in the following subsection; discussions of fuel cell electric vehicles and hybrid electric vehicles are in the Hydrogen subsection and Hybrid Electric subsection, respectively.

Battery Electric Vehicles. Battery power is typically evaluated based upon the power density and energy density of the elements used in the battery, which indicate the power output and energy storage capabilities of the battery. The power and energy densities required to power a battery electric vehicle (BEV) drive train can be provided by the following types of batteries, from the best suited (i.e., greatest power output and energy storage potential) to the least viable (i.e., low power output and energy storage potential):

- Lithium-ion (Li-ion)
- Lithium-metal polymer (LiM-polymer)
- Sodium-nickel chloride (commonly referred to as ZEBRA)
- Nickel-metal hydride (Ni-MH)
- Nickel-cadmium (Ni-Cd)
- Lead-acid batteries

These parameters are important with respect to air quality because they address the efficacy of the electric vehicle to perform work relative to conventional-fuel counterparts (i.e., power density) and the level of off-site energy production or purchases required to keep the vehicles operational (i.e., energy density).

As indicated previously, the advantage of adopting BEVs comes from the defrayal of exhaust emissions generated by the operation of the equipment, albeit acknowledging the emissions that occur off-site due to the generation of additional electricity by fossil-fueled power plants. Notably, the U.S. EPA performed an in-depth study on emissions reductions achievable by replacing existing four-stroke gasoline, LPG, and diesel baggage tractors with BEVs, assuming a worst-case scenario in which additional electricity would be purchased by a coal-fired power plant and a best-case scenario wherein electricity would be generated by a maximally controlled natural gas-fired facility. Figure 3-4 provides an overview of the results. The U.S. EPA's results show the importance of off-site generation of power in evaluating net emission reductions from BEVs (Campanari et al. 2009).

For HC, the U.S. EPA demonstrated that, in the best case, emissions would be reduced between 99.5 and 99.9 percent from those produced from gasoline, LPG, and diesel. In the worst case, HC emissions would be reduced between 92.4 percent (relative to diesel) and 98.2 percent (relative to gasoline). With respect to CO emissions, BEVs offer a 100 percent reduction relative to gasoline

	CO	HC	PM
Gasoline	↓	↓	↓ ↑
Diesel	↓	↓	↓ ↑
LPG	↓	↓	↓ ↑

	NOx	CO_2	HAPs/AT
Gasoline	↓	↓	Highly dependent upon source fuel used at electrical generation facility
Diesel	↓	↓	
LPG	↓	↓	

Figure 3-4. Emission reduction potential/ penalty of BEV compared to conventional and other fuels.

and LPG fuels, and 99.3 percent relative to diesel. Even the worst case offers 99.9 percent reductions with respect to gasoline and LPG fuels, and 96.4 percent with respect to diesel.

Real distinctions begin to appear based on power plant source fuel when evaluating the baggage tractor emission reductions of NO_x, PM, and CO_2 (U.S. EPA 1998):

- Emission reductions of NO_x from BEV, when compared to the best-case, natural gas-fired power plant scenario, are on the order of 97.4 percent (relative to LPG) to 99.4 percent (relative to diesel).
- When considering the worst-case, coal-fired power plant scenario, NO_x reductions from BEV usage equal 18 percent relative to LPG, 38.5 percent when compared to gasoline, and 81.8 percent when considering diesel.
- Indirect BEV PM emissions were found to decrease by 88.9 percent compared to gasoline and LPG GSE in the best-case scenario and by 99.6 percent from levels produced by diesel tractors.
- The worst-case scenario showed PM emissions penalties from BEV operation on the order of 3,328 percent with respect to gasoline/LPG GSE and by 33.8 percent when compared to diesel GSE.
- Baggage tractor BEV reductions of CO_2 relative to gasoline, diesel, and LPG GSE approximate 75 percent when assuming the power is purchased from a natural gas-fired plant, but range between 29.9 percent (relative to LPG) and 41.2 percent (relative to gasoline) when purchased from a coal-fired plant.

Hydrogen. Hydrogen can be used as an alternative fuel in differing ways: (1) as a combustion fuel in internal combustion engines (H_2ICE), (2) as a feed gas in the fuel cell of a fuel cell electric vehicle (FCEV), and (3) as an additive to compatible conventional fuels (Sopena et al. 2010).

Because hydrogen fuel contains no carbon, combustion yields little to no direct CO, HC, and CO_2 emissions (Mohammadi et al. 2007). Researchers found that CO emissions from an SI H_2ICE vehicle decreased with increasing engine speeds, were sourced to thermal degradation of lubrication oil, and were negligible compared to emissions from gasoline SI engines. CO_2 emitted from lubrication oil in the same experiment exhibited the same relationship as CO but without any observable trend with respect to engine speed. When comparing BEVs with FCEVs, CO_2 emissions were found to be up to 46.3 percent less in FCEVs due to the potential for BEVs to be powered with electricity generated from GHG-intensive sources such as coal-fired power plants (Thomas 2000).

NO_x emissions from combustion of H_2ICE fuel is a function of the fuel-to-air ratio of the fuel and can be constrained using NO_x traps, water injection, and EGR applications (Verhelst and Wallner 2009). Researchers have revealed a trade-off between H_2ICE power output and NO_x emission reduction applications such as those listed above (White et al. 2006). Notably, a nearly tenfold decrease in NO_x emissions over those occurring from gasoline combustion was observed for an SI H_2ICE (Kahraman et al. 2007). In comparison to diesel NO_x emissions, H_2ICE emissions from a direct injection CI engine were 20 percent lower than the same engine fueled with conventional diesel (Gomes-Antunes et al. 2009).

When used as a fuel additive to CNG, HC, CO, and CO_2 emissions decreased with increasing percentage of hydrogen blended with the fuel. NO_x emissions increased over those reported for CNG combustion alone but were shown to be corrected using a catalytic converter, EGR, or lean burn techniques (Akansu et al. 2004, Bysveen 2007). PM emissions in the smaller size ranges have been shown to decrease by 85 percent when hydrogen is blended with gasoline (90 percent gasoline, 10 percent hydrogen) in a direct injection engine, only at the expense of forming greater levels of particles in the size range conducive to accumulation. By mass, the overall concentration of PM in the exhaust decreased by 17 percent (Zhao et al. 2010).

Importantly, little data have been generated on the topic of HAPs resulting from the use of hydrogen-fueled vehicles. However, based on observed data for HC emissions, it can be expected that few HAPs are emitted due to combustion processes, and any HAP emissions would be tied to either combustion of the engine lubrication oils and/or the characteristics of fuels with which hydrogen may be blended (i.e., CNG or diesel).

Hybrid Electric. The properties of HEVs depend largely upon the characteristics of the means by which electrical energy is supplied to the vehicle, as well as the type(s) of fossil fuel with which it is hybridized. Hence, it is difficult to provide focused discussion on operational and emission considerations with respect to GSE applications.

Emission reduction potentials and penalties for HEVs are underpinned by the degree to which the vehicle is electrified and by what means, the source of the electrical energy used to power the vehicle, and the fuel(s) with which it is hybridized.

Oxygenated Fuels (i.e., Ethanol, Dimethyl Ether)

Oxygenated fuels contain a significant amount of oxygen in their chemical composition, which typically results in higher fuel combustion efficiency. Due to their volatile nature, oxygenated fuels are seldom used singly but are instead blended with conventional fuels. This subsection presents information on the oxygenated fuels ethanol and dimethyl ether.

Ethanol. Ethanol mixed with a small portion of water (i.e., hydrous ethanol) has been utilized as an alternative fuel additive to methyl tert-butyl ether (MTBE), a known air toxic, in many on-road motor vehicles as a means of increasing the combustion efficiency of conventional fuels such as gasoline.

When blended with conventional diesel fuel in a CI engine, ethanol has been shown to reduce CO and PM emissions but was shown to increase NO_x emissions. However, in contrast, other studies have shown that operating load has a large impact on this trend, showing opposite emissions trends for CO, HC, and NO_x than those identified above. In SI gasoline engines, significant CO and HC emission reductions (up to 90 percent) were observed in gasoline-ethanol blended fuels, at the expense of increased CO_2 emissions due to higher combustion efficiency (up to 25 percent). NO_x emissions were found to be largely dependent on the engine operating conditions and chemical balance of the fuel.

HAP emissions of carbonyl compounds such as formaldehyde and acetaldehyde increase when ethanol is blended into both gasoline and diesel fuels, and tend to increase in concentration with increasing engine speed.

Dimethyl Ether. Dimethyl ether (DME) is a highly oxygenated fuel that is currently being studied for applications as primary fuel in ICEs, as well as an additive to improve the emission parameters of conventional fuels such as diesel (Acroumanis et al. 2008).

Barring application of EGR, injection retardation, or exhaust after-treatments, DME emissions of NO_x are found to be comparable to diesel emissions, but can be reduced to levels lower than diesel when using the above-referenced applications (Acroumanis et al. 2008). When blended with conventional diesel fuels, NO_x emissions were reduced in the DME blends. However, HC and CO emissions measured higher with the DME blends than with diesel alone, but CO_2 emissions from DME blends measured equal to or lower than diesel (Ying et al. 2006).

Because DME is highly oxygenated and contains fewer single carbon-to-carbon bonds compared to traditional fuels such as diesel and gasoline, the potential for PM formation to occur due to its combustion is greatly reduced (Sidhu et al. 2001). Emissions of HAPs from combusted DME approximate those of other oxygenated fuels such as CNG and are comprised of benzene, toluene, ethylbenzene, styrene, benzaldehyde, naphthalene, acenaphthene, benzofluoranthene, benzo(e)pyrene, and indeno(1,2,3-c,d)pyrene (Sidhu et al. 2001).

3.4.3 Environmental Considerations and Challenges with Other Environmental Media

Potential impacts of alternative-fuel utilization on areas of environmental concern other than air quality, including those related to water resources, soils, odor, and human health, are presented in this subsection. Climatic effects on the feasibility of usage with respect to these alternative fuels are also addressed, where applicable.

Biodiesel

Soil and Water Resources. Biodiesel fuel biodegrades up to four times faster than conventional petroleum diesel fuel. If leaked or spilled into the environment, biodiesel does not present the same level of soil, surface water, and groundwater contamination concerns typically associated with gasoline and diesel fuels, making it ideal for use in environmentally sensitive areas such as wetlands, marine environments, and national parks.

Human Health and Environmental Safety. The flashpoint for biodiesel is higher than 300°F (150°C), compared with about 125°F (52°C) for petroleum diesel, making biodiesel relatively safe for workers to handle, store, and transport. Recently, the U.S. Department of Labor Mining Safety Health Administration (MSHA) has implemented rules for underground mines that limit workers' exposure to diesel PM. However, MSHA found that switching from petroleum diesel fuels to high blend levels of biodiesel (B50 to B100) significantly reduced PM emissions from underground diesel vehicles and substantially reduced workers' exposure.

Pure biodiesel can be extinguished with dry chemical, foam, halon, CO_2, or water spray, although the water stream may splash the burning liquid and spread fire. Oil-soaked rags used in association with biodiesel can cause spontaneous combustion if they are not handled properly. Before disposal, rags should be washed with soap and water and dried in well-ventilated areas.

Because biodiesel will burn if ignited, it must be kept separate from oxidizing agents, excessive heat, and ignition sources. No placards or warning signs are required for the transport of pure biodiesel. However, biodiesel blends with diesel and kerosene are required to be transported in placarded trucks if the flash point of the blend is lower than 200°F (93°C), according to U.S. DOT regulations. If the flash point is lower than 140°F (60°C), the liquid is considered flammable and the Hazard Class 3 flammable placard is required. Local fire regulations determine the requirements for signage on storage containers, but typically, tanks containing fuels (including B100) must be labeled with National Fire Protection Association diamonds. The

National Fire Protection Association diamonds will indicate whether the fuel is flammable or combustible.

Odor. Biodiesel is non-toxic and has a mild, somewhat pleasant odor. When burned, the fuel emits a fried-food or barbecue odor.

Climatic Considerations. Biodiesel is the more susceptible to the cold than many other alternative fuels due to "gelling." The most effective way to winterize biodiesel fuel is to blend it with petroleum diesel. Anti-gel additives chemically alter the fuel to inhibit the formation of wax crystals, but some reportedly work more effectively than others. The actual source of biodiesel will change its cold weather performance as well. For example, palm oil biodiesel will gel at very high temperatures, whereas algae- or camelina-derived biodiesel will gel at lower temperatures making them more appropriate for cold weather use.

B20 blends are used mostly in very cold climates, such as northern Minnesota and Wyoming, where temperatures routinely fall below −30°F (1°C) in the winter. B20 has also been used for several years in the Boston Logan International Airport shuttle fleet with no winter problems. Other users have reported using B100 in extremely cold climates, such as in Yellowstone National Park. There the vehicles are equipped with winterization packages, and no other precautions were noted.

Another cold climate option is heating the fuel or the engine. Heated fuel filters are available that run off an engine battery or can be plugged into a standard outlet. There are also heating pads and heating probes that can be applied to the fuel tank, again running off a 12-volt battery or standard current. An electric block heater (a heating element that is installed in the engine block and immersed in the coolant) is another solution. Block heaters warm the entire engine to ease starting. They typically operate on standard current and can remain plugged in for hours or overnight during bitterly cold conditions.

Compressed Natural Gas

Soil and Water Resources. Natural gas is relatively non-toxic, non-corrosive, and non-carcinogenic. It is also lighter than air, which results in the gas dissipating quickly in the event of a leak. Thus, accidental discharges of natural gas will not contaminate soil and water like spills of gasoline and diesel. In addition, the risk of uncontrolled combustion is reduced because of the higher flash point of natural gas compared to other petroleum fuels.

Odor. Raw natural gas is odorless, so a distinctive odorant is added prior to distribution. This strong odor makes the presence of a leak very easy to detect.

Climatic Considerations. With no major climatic drawbacks, CNG is among the best performing cold weather alternative fuels.

Liquefied Petroleum Gas

Soil and Water Resources. Propane is an approved "clean fuel" listed in the federal CAA and the Energy Policy Act. It is non-toxic and vaporizes at ambient temperatures. Because of these properties, the placement of propane tanks either above or below ground is not regulated by the U.S. EPA.

Odor. As propane is virtually odorless and colorless in its natural state, a commercial odorant, ethyl mercaptan, is added to the gas.

Climatic Considerations. Cold temperatures reduce the vapor pressure of propane. However, there are no reported problems with its ignition in cold weather.

Electricity

Soil and Water Resources. Electric vehicles themselves present no direct threat to surface water, groundwater, and soils. However, battery disposal is a potential risk and tightly controlled by hazardous waste regulatory requirements. Moreover, the battery recycling and reuse market is rapidly expanding, as it did for lead-acid batteries in the past. Lithium batteries are more difficult to dispose of, but procedures for recycling exist and are becoming more cost effective. The components of nickel-metal hydride batteries used in most electric drive vehicles are also recyclable, but the necessary infrastructure is still limited. Owners of equipment that uses batteries containing sulfuric acid and/or lead must comply with annual chemical reporting requirements under the regulations of the U.S. EPA Superfund Amendments and Reauthorization Act of 1986 (aka Emergency Planning and Community Right-to-Know Act).

Human Health and Environmental Safety. With respect to health and safety, electric drive vehicles must meet the same safety standards required for conventional-fuel vehicles sold in the United States. The exceptions are non-road vehicles, which are subject to less-stringent standards because they are typically limited to non-public roadways.

Most electric vehicles are designed with safety features that deactivate the electric system in the event of an accident. For example, many are designed with cutoff switches to isolate the battery and disable the electric system, and all high-voltage power lines are colored orange for identification.

In addition, EVs tend to have a lower center of gravity than conventional vehicles, making them less likely to roll over.

Odor. Electric engines produce no odor with the exception of an "ozone" smell in rare circumstances.

Climatic Considerations. As discussed previously, battery performance is adversely affected by cold, especially those of the lead-acid variety. Common remedies include battery insulation, a block heating system, or installation of an oversize starting battery. New battery technologies promise to improve on the cold weather problem.

Hydrogen

Soil and Water Resources. Hydrogen is a very small molecule with low viscosity and is therefore prone to leakage. However, it is considerably lighter than gasoline vapor and air and therefore disperses quickly into the atmosphere. As a result, it does not represent a significant source of soil or water contamination.

Human Health and Environmental Safety. Hydrogen is non-toxic and non-poisonous; however, in a confined space, leaking hydrogen can accumulate and reach flammable concentrations. It is also an asphyxiant in sufficient concentrations. In a closed environment, leaks of any size are a concern, since hydrogen cannot be easily detected. Proper ventilation and the use of detection sensors can mitigate these hazards.

Hydrogen gas is compressed and stored at high pressures. For safety, hydrogen tanks are equipped with pressure relief devices.

As a liquid, hydrogen is stored at −423°F, a temperature that can cause cryogenic burns or lung damage. Detection sensors and personal protective equipment are critical when dealing with a potential liquid hydrogen leak or spill.

Odor. Hydrogen is odorless. However, odorants are not used because there are no known odorants light enough to "travel with" hydrogen at the same dispersion rate. Current odorants also contaminate fuel cells, which are an important application for hydrogen.

Climatic Considerations. Because a singular design for hydrogen-powered engines has not yet been selected and cold weather performance varies by design and application, the climatic effects are not known. Ideal hydrogen fuel cells produce only water vapor as a byproduct. Therefore, fuel cells run the risk of freezing in the cold.

Hybrid Electric

Many environmental properties of electric vehicles apply to hybrid electric vehicles, especially with respect to battery replacement and operation in cold weather climates. Refer to the subsection on electricity for this information.

Ethanol

Soil and Water Resources. Ethanol is biodegradable and, if spilled, poses much less of a threat than petroleum to surface water, groundwater, and soils.

Human Health and Environmental Safety. Ethanol (E85) is poisonous and flammable, should never be confused with beverage alcohol, and should be kept from open ignition sources. Fuel vapors can travel along the ground or be moved by ventilation and ignited by sources such as pilot lights, sparks, electric motors, static discharge, and other ignition sources at locations distant from material handling. In general, the same safety standards that apply to gasoline apply to E85.

Odor. Ethanol exhibits a distinctly unpleasant (i.e., pungent) odor.

Climatic Considerations. In cold weather climates, high ethanol blends present a problem to achieve enough vapor pressure for the fuel to evaporate and spark the ignition. However, E85 is considered to be the maximum blend to help mitigate this problem. At places where temperatures consistently fall below 10°F (−12°C), it is recommended that an engine heater system be installed.

3.5 GSE Tutorial

To provide GSE stakeholders with the necessary information, data, and supporting materials to better understand, manage, and achieve meaningful reductions in GSE emissions, the relevant outcomes of this research are consolidated into a GSE Tutorial. Provided on the accompanying CD, this tutorial is a user-friendly, interactive, and self-paced tool for learning more about GSE and their functions and alternative fuels and their emission reduction potentials. Users can "point and click" their way through convenient, easy-to-follow synopses of the materials in a fashion that will help the user synthesize and apply the knowledge to real-world practice. To this end, the tutorial is structured in three modules, briefly summarized as follows:

- **Module 101, GSE Basics:** Topics covered in this module include the types and functions of GSE, usage considerations, potential alternative fuels that could be used in GSE to reduce air quality impacts of their operation, environmental regulations and programs that pertain to GSE ownership and operation, and a primer of air quality science and policy principles.
- **Module 201, Emissions Reduction Approaches and Case Studies:** Building on Module 101, this module addresses emissions reduction approaches applicable to GSE, including infrastructure improvements, vehicle retrofitting, alternative-fuel usage, and operation/maintenance strategies. Additionally, airport and airline case studies on the topics covered in this module are also presented.
- **Module 301, Converting to Cleaner GSE:** The intent of this module is to present the "big picture" of GSE ownership and environmental impact mitigation strategies related to their use. The module summarizes the economic costs and environmental trade-offs of using cleaner GSE

(where available), lists available vendors and distributors of both conventional- and alternative-fuel GSE, and presents life-cycle (i.e., "well to wheels") considerations that GSE owners and operators should keep in mind during their decision-making processes.

3.6 GSE Inventory

The estimate of the nationwide GSE inventory was developed under Task 7 using data collected from three general sources:

- Field surveys of selected airports were conducted to get a hands-on count of the number of GSE that could be found at large-hub, medium-hub, small-hub, and non-hub airports in varying climate conditions with potentially different equipment requirements. Correlations between the GSE inventories at these airports with several parameters were evaluated. The best fit correlations for total GSE and for individual GSE types were selected and applied to a list of airports to estimate the national GSE inventory.
- GSE data provided by participating airlines were aggregated and estimates of the national inventory were made based on commercial aircraft operations. Comparison of the national inventory with this approach is made to the national inventory determined from the field survey correlations and is used to provide some idea of the uncertainty in the national GSE inventory estimates.
- Finally, several GSE inventories that had been developed previously for individual airports were obtained and subjected to the correlations developed from the field surveys. The results of this comparison are also used to provide context regarding the uncertainty of the national GSE inventory estimates.

3.6.1 Airport Field Surveys and Data Evaluation

Survey Methods and Results

The research team contacted a number of airports to identify those that were interested in participating in this project by allowing team members to conduct field surveys of airport GSE. The final selection of airports was made to include large-hub, medium-hub, small-hub, and non-hub airports in warm and cold weather areas. The 12 surveyed airports and their survey dates are listed in Table 3-13.

The first airport surveyed was Dallas-Fort Worth (DFW). Because of its size and level of activity, a detailed DFW GSE Survey Plan was developed and used in most of the subsequent surveys. For most medium-hub and large-hub airports, the field surveys were coordinated with the airport staff and, at the larger airports, took place during low-activity periods. These low-activity periods were either in the late-night/early-morning hours or later in the morning after the first flights of the day had departed.

The surveyors attempted to collect the GSE type, make and model, fuel type, and year of manufacture for each piece of equipment. Initially, the horsepower was also one of the intended data elements to be collected. However, most GSE surveyed did not have engine power readily displayed, so this element was not collected on most equipment.

The field teams recorded survey information on field logs and then transcribed the logs to electronic files (e.g., Microsoft® Word and Excel files). These data were also later reviewed by the field and the statistical teams, and several necessary modifications were made to facilitate the statistical evaluation. Table 3-14 provides the total GSE counts that were aggregated to create the field survey GSE database for all airports surveyed.

The summary of the aggregated data by GSE type is provided in Table 3-15. Initially, the teams were identifying approximately 30 GSE types during the surveys. However, to facilitate

Table 3-13. Airports surveyed for GSE.

Airport	Size Category[a]	Weather Category[b]	Dates Surveyed (2011)
Boise (BOI)	Small Hub	Cold	July 26
Boston Logan (BOS)	Large Hub	Cold	July 28
Dallas-Ft Worth (DFW)	Large Hub	Warm	May 23 & 24
Detroit Wayne County (DTW)	Large Hub	Cold	July 27 & 28
Fresno-Yosemite (FAT)	Small Hub	Warm	July 12
Front Range (FTG)	Non-Hub	Cold	May 3
Manchester (MHT)	Medium Hub	Cold	July 28
Minneapolis-St. Paul (MSP)	Large Hub	Cold	June 23
Sacramento International (SMF)	Medium Hub	Warm	July 13
Seattle-Tacoma (SEA)	Large Hub	Warm	June 21
Tampa Bay (TPA)	Large Hub	Warm	August 26
Tucson International (TUS)	Medium Hub	Warm	June 14

[a] 2010 size designations from FAA.
[b] Airports were designated warm or cold based on the number of days with temperatures below 32°F (i.e., < 50 days = warm).

Table 3-14. GSE count by airport.

Airport	No. of GSE
Boise (BOI)	321
Boston Logan (BOS)	1,704
Dallas-Ft Worth (DFW)	2,323
Detroit Wayne County (DTW)	890
Fresno-Yosemite (FAT)	124
Front Range (FTG)	48
Manchester (MHT)	235
Minneapolis-St. Paul (MSP)	1,952
Sacramento International (SMF)	513
Seattle-Tacoma (SEA)	1,026
Tampa Bay (TPA)	734
Tucson International (TUS)	155
Total Surveyed GSE	**10,025**

Table 3-15. GSE counts by GSE type.

GSE Type	No. of GSE	Percentage of Fleet
Air Conditioners/Heaters	312	3.1%
Air Start Units	160	1.6%
Aircraft Tractors/Tugs	705	7.0%
Belt Loaders	1,102	11.0%
Baggage Tugs	2,575	25.7%
Buses	69	0.7%
Cars/Pickups/Vans/SUVs	1,132	11.3%
Carts	330	3.3%
Cargo Loaders	281	2.8%
Cabin Service/Catering Trucks	320	3.2%
Deicing Trucks	399	4.0%
Forklifts	314	3.1%
Fuel Trucks	151	1.5%
Ground Power Units/Generators/GPU-ACs	487	4.9%
Hydrant Carts/Hydrant Trucks	62	0.6%
Lavatory Carts/Lavatory Trucks	177	1.8%
Light Carts	111	1.1%
Lifts	344	3.4%
Maintenance Trucks	56	0.6%
Other	843	8.4%
Passenger Stairs	95	0.9%
Total	**10,025**	**100.0%**

the statistical evaluation, several type categories were combined to provide a sufficient number of data points in a category to develop meaningful evaluations.

Finally, the GSE type data differentiated by fuel type is summarized in Table 3-16. The field survey teams occasionally had difficulty determining the fuel type for some equipment. Filler caps for some equipment may have been located under a hood or otherwise covered, thus not visible during the survey. In some cases, the participating airport or an airport tenant provided data on equipment that did not include fuel type, and the equipment was not physically observed during the survey. This resulted in a moderate amount (almost 15 percent) of unknown fuel type counts in the field survey inventory.

During the surveys, diesel fuel types were simply identified by the color or labels on the filler cap. The team was not able to determine whether the diesel was strictly petroleum based or biodiesel. Diesel that is 85 percent to 100 percent biodiesel (B85-B100) is defined as an alternative fuel under DOE EPAct guidelines and is potentially eligible for grant funding under FAA's VALE Program (see Section 3.2.6 of this report). Therefore, note that the ratio of alternative fuels to conventional fuels (petroleum diesel and gasoline) will be understated in this report.

The distribution of GSE fuel types by airport—after unknown fuel types were removed and the fuel type distributions recalculated—is summarized in Figure 3-5. The use of alternative fuels (electric, propane, natural gas, and solar) range from 1 percent to 34 percent for the airports surveyed, with electric motors/battery power being the most prevalent of alternative-fuel equipment.

Table 3-16. GSE counts by type and fuel.

		Fuel Type Percentage by GSE Type						
GSE Type	**Total**	**Diesel[a]**	**Electric**	**Gasoline**	**LPG**	**NG**	**Solar**	**Unk[b]**
Baggage Tugs/Cargo Tugs	2,575	15.4%	16.7%	52.7%	2.8%	0.0%	0.0%	12.3%
Cars/Pickups/SUVs/Vans	1,132	4.9%	0.5%	83.9%	0.1%	0.1%	0.0%	10.5%
Belt Loaders	1,102	25.0%	14.7%	44.6%	0.5%	0.4%	0.0%	14.8%
Other	843	52.2%	4.0%	28.4%	1.5%	0.2%	0.0%	13.6%
Aircraft Tractors/Tugs	705	67.7%	11.1%	8.2%	0.0%	0.0%	0.0%	13.0%
Generators/GPUs/GPU-ACs	487	61.0%	9.9%	7.2%	0.0%	0.2%	0.0%	21.8%
Deicing Trucks	399	64.7%	0.8%	26.6%	0.0%	0.0%	0.0%	8.0%
Lifts	344	21.8%	26.2%	26.7%	5.5%	0.0%	0.0%	19.8%
Carts	330	1.2%	77.6%	5.5%	0.9%	0.0%	0.0%	14.8%
Cabin Service/Catering Trucks	320	52.2%	0.3%	15.3%	0.0%	0.0%	0.0%	32.2%
Forklifts	314	12.7%	8.6%	13.7%	44.9%	0.0%	0.0%	20.1%
Air Conditioners/Heaters	312	76.3%	2.6%	11.5%	0.0%	0.0%	0.0%	9.6%
Cargo Loaders	281	78.6%	0.4%	7.5%	0.4%	0.0%	0.0%	13.2%
Lavatory Trucks/Lavatory Carts	177	17.5%	7.9%	59.9%	0.0%	0.6%	0.0%	14.1%
Air Start Units	160	71.9%	0.6%	2.5%	0.0%	0.0%	0.0%	25.0%
Fuel Trucks	151	64.9%	2.0%	8.6%	0.0%	0.0%	0.0%	24.5%
Light Carts/Light Stands	111	64.9%	1.8%	7.2%	0.0%	0.0%	9.0%	17.1%
Passenger Stairs	95	31.6%	1.1%	42.1%	1.1%	0.0%	0.0%	24.2%
Buses	69	21.7%	0.0%	7.2%	0.0%	55.1%	0.0%	15.9%
Hydrant Carts/Hydrant Trucks	62	61.3%	0.0%	22.6%	0.0%	0.0%	0.0%	16.1%
Maintenance Trucks	56	28.6%	0.0%	44.6%	0.0%	0.0%	0.0%	26.8%
Surveyed GSE Average	**10,025**	**33.5%**	**11.6%**	**37.0%**	**2.6%**	**0.5%**	**0.1%**	**14.7%**

[a] Diesel fuel types were simply identified by the color or labels on the filler cap. The research team was not able to determine whether the diesel was strictly petroleum based or biodiesel. Diesel that is 85 percent to 100 percent biodiesel (B85-B100) is defined as an alternative fuel under DOE EPAct guidelines and is potentially eligible for grant funding under FAA's VALE Program (see Section 3.2.6 of this report). Therefore, note that the ratio of alternative fuels to conventional fuels (petroleum diesel and gasoline) will be understated in this table.

[b] Unk = Unknown, unable to determine during survey.

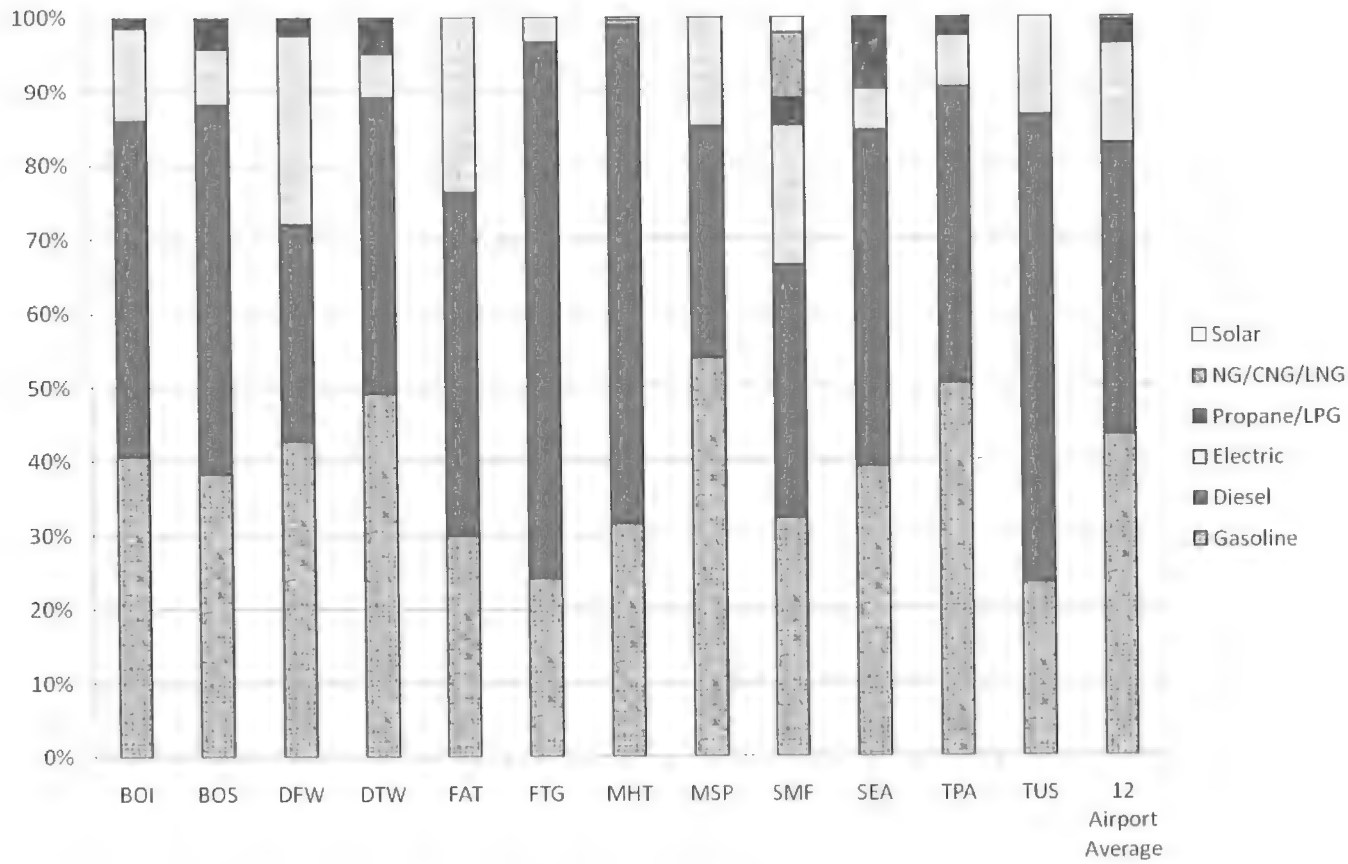


Figure 3-5. GSE fuel type distribution by surveyed airport.

The distribution of fuel types by airport shown on Figure 3-5 indicates that only three of the surveyed airports had more than 20 percent alternative fuels. Comparing the air quality nonattainment designations for the surveyed airports indicates that regions around the Dallas-Fort Worth (DFW), Fresno-Yosemite (FAT), and Sacramento (SMF) airports may have the worse air quality of the 12 surveyed airports. The region around DFW is classified as serious for ozone (smog) nonattainment; the region around FAT is classified as extreme (worst classification) for ozone and nonattainment for particulate matter ($PM_{2.5}$); and the region around SMF is classified as severe for ozone nonattainment and nonattainment for particulate matter (both $PM_{2.5}$ and PM_{10}). Only three other surveyed airports are in ozone nonattainment areas, and the classification for ozone in these areas is marginal or moderate. Regulations impacting mobile source emissions in the Dallas-Fort Worth, Fresno, and Sacramento areas may have influenced the conversion or selection of alternative-fuel equipment.

Statistical Analysis

Using the GSE inventories from the surveyed airports, a number of potential correlations between the GSE counts and airport activity and climate parameters were evaluated. The major parameters included total operations, commercial operations, and enplaned passengers, as well as several metrics to represent the effect of cold climates. Regarding the weather parameters, the researchers had obtained anecdotal information indicating that more GSE were needed in cold weather airports due to the impact of this type of weather on the operation and maintenance of equipment (i.e., the equipment required more time for repair and maintenance; thus, more equipment was needed to service flights).

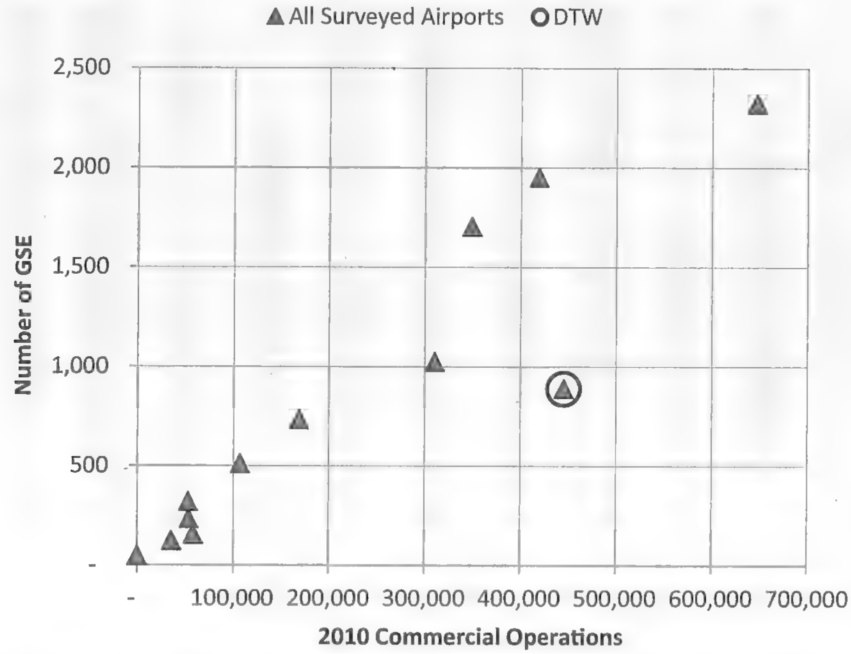


Figure 3-6. Number of GSE versus 2010 commercial operations by airport.

The GSE inventories for the 12 surveyed airports are plotted against 2010[1] commercial operations on Figure 3-6. From this plot it can be seen that the relative number of GSE at the Detroit Metropolitan Wayne County Airport (DTW) per aircraft operation were substantially lower than the other airports. This was likely due to severe weather that occurred during the survey, closing down the airport for most of the survey period. Therefore, the DTW inventory was not used in the correlations developed below.

A series of equations were then analyzed with the total GSE counts to determine which of them provided reasonable results in terms of correlation coefficients and percent differences from measured counts. From this series, six equations that provided the best fits were analyzed for total GSE and for each GSE type category:

Eq. 2: P1 × Total Enplanements (in millions)
Eq. 6: P1 × Commercial Operations (in millions)
Eq. 7: P1 × Total Enplanements (in millions) + P2 × Commercial Operations (in millions)
Eq. 8: P1 × Commercial Operations (in millions) + P2 × Climate Code × Total Operations (in millions)
Eq. 13: P1 × Commercial Operations (in millions) + P2 × Climate Code × Commercial Operations (in millions)
Eq. 22: P1 × Commercial Operations (in millions) + P2 × Temperature Parameter

The P1 and P2 values are best fit constants determined statistically; the Climate Code is a value of 1 for cold airports[2] and a value of 0 for warm airports; and the Temperature Parameter is the

[1]The 2010 airport operations databases were the most current databases available when this evaluation was being conducted. It was assumed that the GSE fleet information collected in 2011 would be fairly representative of the fleet in 2010.

[2]The definition of a cold airport was one where temperatures dropped below 32°F (based on National Oceanic and Atmospheric Administration databases) on 50 days or more annually; all other airports were defined as warm.

average temperature in January for the given airport. It should be noted that Total Enplanements, Commercial Operations, and Total Operations are not completely independent parameters. The Climate Code and Temperature Parameter are independent parameters from the others. Therefore, only Equation 22 analyzes the correlation with two independent parameters, Equations 2 and 6 analyze the correlations with one parameter, and the remaining equations analyze the correlations with a hybrid set of parameters.

These equations were initially applied to the aggregate GSE total at each airport and then applied to the individual GSE categories at each airport. The following list presents the assumptions used to develop the linear correlations:

- GSE inventories from 12 airports (BOI, BOS, DFW, DTW, FAT, FTG, MHT, MSP, SEA, SMF, TPA, and TUS) were reviewed, and the inventory from DTW was dropped from further evaluation since it was undercounted due to severe weather during the survey.
- The linear, least squares regressions were performed with SYSTAT v.13 software.
- One to three airport activity and/or climate parameters were used in the initial screening equations.
- After the initial screening of potential regression equations, the equations selected for final comparisons would be those with no more than two parameters.
- All regression lines would go through the origin (0,0) meaning that no activity would correspond with no GSE.
- Final selection of the best fit equation for each type of GSE was determined by the researchers after they reviewed the coefficient of determination (R^2 value) and percent differences.

Table 3-17 presents the statistically determined P1, P2, and R^2 values, as well as the percent differences from the surveyed inventory, for each of the six best fit equations listed previously.

The comparison of the calculated total GSE for each of the 11 airports used from the field survey with the actual survey results is shown on Figure 3-7. When the individual GSE types were analyzed, the best fit equation was either Equation 7 or Equation 8. The best fit coefficients (P1 and P2) for the selected equation for each GSE type, as well as the coefficient of determination and percent difference from the surveyed inventories, are presented in Table 3-18.

National GSE Inventory Estimate

Once the best fit equation and parameters were determined for each GSE type, the selected equations were applied to over 500 U.S. airports, which represent approximately 99 percent of the commercial operations nationwide in 2010. Since the fit equations were linear, sums of the parameter quantities (i.e., Total Enplanements, Commercial Operations, and Climate Code Total Operations) over all 500+ airports were used to calculate national GSE inventories by GSE type. The enplanements and operations data were obtained from the Operations Network (OPSNET), Air Traffic Activity Data System (ATADS), Enhanced Traffic Management System Counts (ETMSC), and Terminal Area Forecast (TAF) databases maintained by the FAA. The estimated national inventory of GSE by type is presented in Table 3-19.

Table 3-17. Best fit correlation constants for total GSE at 11 surveyed airports.

Equation No.	P1	P2	Correlation (R^2)	% Diff from Counted
2	93.4	NA	0.948	−5.71%
6	4010	NA	0.978	−3.38%
7	−79.5	7350	0.985	−3.12%
8	3600	1090	0.997	−0.60%
13	3600	1160	0.996	−2.09%
22	4040	−0.469	0.978	−4.18%

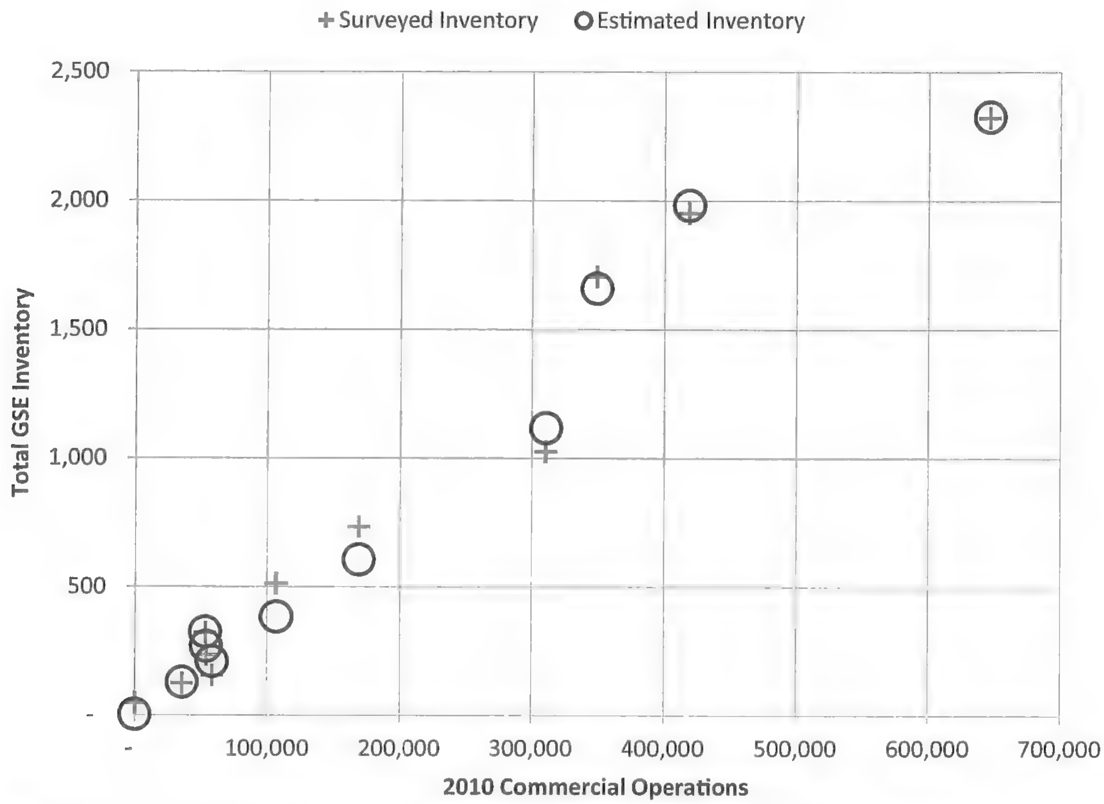


Figure 3-7. Comparison of estimated to surveyed GSE inventories.

Table 3-18. Best fit equations for total GSE and individual GSE types at 11 airports.

GSE Type	Selected Equation	P1	P2	Coefficient of Determination (R^2)	% Difference*
Total GSE	8	3603	1086	0.997	−0.6%
Air Conditioners/Heaters	8	80.8	102	0.667	+15.8%
Air Start Units	7	3.19	−76.3	0.921	−9.4%
Aircraft Tractors/Tugs	8	231	108	0.980	+5.4%
Belt Loaders	8	417	36.9	0.990	−2.6%
Baggage Tugs/Cargo Tugs	8	1182	−84.5	0.978	+7.4%
Buses	7	1.30	−36.2	0.179	−41.0%
Cars/Pickups/Vans/SUVs	8	385	191	0.949	+4.6%
Carts	8	115	65.1	0.757	+6.0%
Cargo Loaders	7	1.90	26.4	0.897	−8.4%
Cabin Service/Catering Trucks	7	−4.12	315	0.952	+9.8%
Deicing Trucks	8	131	116	0.976	+18.6%
Fork Lifts	7	−7.60	453	0.932	+1.5%
Fuel Trucks	8	45.2	17.6	0.813	−11.8%
Generators/GPUs/GPU-ACs	7	4.58	−24.9	0.823	−19.0%
Hydrant Trucks/Hydrant Carts	7	−2.10	115	0.654	−1.7%
Lavatory Trucks/Lavatory Carts	7	0.376	51.8	0.960	−5.9%
Light Carts/Light Stands	7	1.33	−21.4	0.730	−24.1%
Lifts	8	93.4	119	0.935	+19.5%
Maintenance Trucks	8	10.6	15.9	0.424	+10.3%
Other	8	166	290	0.670	−7.0%
Passenger Stairs	8	22.0	25.0	0.667	−7.1%

* % Difference = 100% × (Calculated GSE – Inventoried GSE)/Inventoried GSE.

Table 3-19. Estimated national GSE inventory by GSE categories.

GSE Type	Calculated National Number of GSE	Percentage of Fleet
Baggage Tugs/Cargo Tugs	25,367	23.6%
Cars/Pickups/Vans/SUVs	13,361	12.4%
Other	10,566	9.8%
Belt Loaders	10,494	9.7%
Aircraft Tractor/Tugs	7,857	7.3%
Deicing Trucks	5,732	5.3%
Fork Lifts	5,078	4.7%
Lifts	4,917	4.6%
Cabin Service/Catering Trucks	4,373	4.1%
Air Conditioners/Heaters	4,238	3.9%
Carts	4,168	3.9%
Generators/GPUs/GPU-ACs	2,679	2.5%
Cargo Loaders	1,963	1.8%
Lavatory Trucks/Lavatory Carts	1,465	1.4%
Fuel Trucks	1,454	1.4%
Hydrant Trucks/Hydrant Carts	1,181	1.1%
Passenger Stairs	1,089	1.0%
Maintenance Trucks	616	0.6%
Air Start Units	500	0.5%
Light Carts/Light Stands	454	0.4%
Buses	86	0.1%
Totals	**108,578**[a]	**100.0%**[b]

[a] Value shown for total GSE was determined by using Equation 8. If individual GSE type totals are summed, the total GSE value would be 107,636. Therefore, the difference between applying Equation 8 to total GSE and summing the individual GSE type totals is only about 1 percent.

[b] The GSE type percentages are based on the sum of the individual types, or 107,636 total pieces of equipment.

3.6.2 Airline-Provided Data

The research team contacted U.S. air carriers and other owners of GSE, primarily through contacts within Airlines for America (A4A, formerly the Air Transport Association). GSE data sets for seven individual airlines were provided. The data sets collected from these carriers were used to analyze the aggregated GSE fleet mix and to develop a second estimate of the nationwide GSE inventory for the purpose of providing some context on the uncertainty of the estimated national inventory developed from the field survey data.

GSE Fleet Mix Summaries

These data were aggregated and are summarized by GSE type in Table 3-20. The airline-provided fleet mix of GSE types is also compared to the mix obtained from the 12-airport field survey (see Table 3-14).

Both field survey and airline-provided data indicate that over 25 percent of the GSE fleet is in the baggage tugs/cargo tugs category, roughly twice as much as the next highest GSE type. The top six GSE types for airline-provided inventories include baggage tugs/cargo tugs, belt loaders, cars/pickups/vans/SUVs, aircraft tractors/tugs, other (e.g., runway maintenance, snow removal, grounds maintenance, and miscellaneous equipment), and carts. The top six types from the surveyed airports include baggage tugs/cargo tugs, cars/pickups/vans/SUVs, belt loaders, other, aircraft tractors/tugs, and generators/GPUs/GPU-ACs. While there is some variation in the order of the categories between the two data sets, the top six categories represent approximately 68 percent, or two-thirds, of the aggregated GSE fleet in both data sets.

Table 3-20. Airline-provided[a] GSE counts by GSE type.

GSE Type	From Airline-Provided Data		Percent (& Rank) of GSE Fleet from Airport Surveys
	No. of GSE	Percent (& Rank) of GSE Fleet	
Air Conditioners/Heaters	901	4.5% (8)	3.1% (12)
Air Start Units	447	2.2% (14)	1.6% (15)
Aircraft Tractors/Tugs	1,786	8.8% (4)	7.0% (5)
Belt Loaders	2,632	13.0% (2)	11.0% (3)
Baggage Tugs/Cargo Tugs	5,361	26.5% (1)	25.7% (1)
Buses	65	0.3% (20)	0.7% (19)
Cars/Pickups/Vans/SUVs	1,900	9.4% (3)	11.3% (2)
Carts	1,028	5.1% (6)	3.3% (9)
Cargo Loaders	198	1.0% (16)	2.8% (13)
Cabin Service/Catering Trucks	492	2.4% (13)	3.2% (10)
Deicing Trucks	635	3.1% (11)	4.0% (7)
Forklifts	728	3.6% (10)	3.1% (11)
Fuel Trucks	79	0.4% (18)	1.5% (16)
Generators/GPUs/GPU-ACs	960	4.7% (7)	4.9% (6)
Hydrant Trucks/Hydrant Carts	–	0.0% (21)	0.6% (20)
Lavatory Trucks/Lavatory Carts	588	2.9% (12)	1.8% (14)
Light Carts/Light Stands	79	0.4% (19)	1.1% (17)
Lifts	784	3.9% (9)	3.4% (8)
Maintenance Trucks	95	0.5% (17)	0.6% (21)
Other	1,204	6.0% (5)	8.4% (4)
Passenger Stairs	260	1.3% (15)	0.9% (18)
TOTAL	**20,222**	**100.0%**	**100.0%**

[a] Counts shown are for GSE inventories provided by seven U.S. air carriers.

The airline-provided data are also summarized by fuel type in Table 3-21. Included in this table is a comparison to the fuel type distribution from the 12-airport field survey (see Table 3-16).

As noted in Section 3.6.1, fuel type for almost 15 percent of the equipment surveyed at the 12 airports was unknown. On the other hand, the airline-provided data usually included fuel type for each piece of equipment; only 0.5 percent of the aggregated airline-provided data set were unknown. Therefore, the airline-provided fuel data provide a reasonable fuel-type distribution for those airlines participating in the study.

Table 3-21. GSE fuel type distributions.

Fuel Type	From Airline-Provided Data		From Field Surveys (12 Airports)	
	No. of GSE	Percentage of GSE Fleet	No. of GSE	Percentage of GSE Fleet
Gasoline	7,761	38.4%	3,712	37.0%
Diesel	7,243	35.8%	3,359	33.5%
Electric	4,306	21.3%	1,166	11.6%
Propane/LPG	645	3.2%	257	2.6%
Natural Gas	158	0.8%	48	0.5%
Solar	–	0.0%	10	0.1%
Unknown	109	0.5%	1,473	14.7%
Totals	**20,222**	**100.0%**	**10,025**	**100.0%**

Comparing the fuel distributions from the two data sets does show some similarities. Specifically, the ranking of fuel type is identical for both (ignoring the data in the "unknown" fuel-type category); from highest to lowest, the use is gasoline, diesel, electric, propane/LPG, natural gas, and solar. Gasoline and diesel account for over 70 percent of the fuel type distribution from all GSE in both data sets.

The electric GSE mix in the airline-provided data is more than twice the electric GSE mix in the field survey data. Several reasons may contribute to this difference: the unknown fuel types for the field survey data, the regulatory environment where the airports were surveyed, and the policies of the airlines providing GSE information.

Based on the field survey approach for determining fuel type (observation of filler cap colors or labels), the unknown fuel types in the surveyed data may include a larger proportion of electric GSE because those units would not have fuel filler caps. However, some of the data obtained at several airports were provided by the airport operator or a tenant in the form of hardcopy printouts that did not include fuel type. The fuel type for equipment data collected in this manner is likely to be more similar to the known fuel-type distribution.

As noted in Section 3.6.1, regulations may affect the conversion of GSE to alternative fuels; thus three of the airports surveyed have a larger portion of non-conventional-fuel GSE. The other airports are likely to see conversions to alternative fuels, but at a slower rate than those in nonattainment areas. Thus the surveyed data may be indicative of the fuel-type distribution nationally.

Finally, only seven airlines are represented in the airline-provided GSE database. It is possible that the major contributors to these data sets have moved to more alternative fuels through economic analysis, policy decisions, and environmental constraints in key hubs.

Overall, the field survey and airline inventories indicate that between roughly 15 to 25 percent of the national GSE fleet was powered by alternative fuels at the time of this evaluation. The most prevalent of these alternative-fuel GSE are electric equipment.

Alternative National GSE Inventory Estimate

The research team estimated a national GSE inventory using the airline-provided GSE counts. Since there appeared to be some difference in GSE count per operation by carrier category, the team chose to split the activity by major carrier and commuter airlines. The total operations by airline for 2010 were obtained from the Bureau of Transportation Statistics Research and Innovative Technology Administration. Specifically, the Air Carrier Statistics T-100 Segments database for all carriers was downloaded. The operations from domestic airports were determined for each of the seven airlines providing data, and then combined into two groups: major carriers (five airlines) and commuter carriers (two airlines). The total GSE inventory for each group was determined from the airline-provided data. Finally, the total commercial operations in the United States for over 500 airports were split into air carrier and commuter/air taxi components. Roughly, the airports database indicated that a total of 13 million commercial operations were by major carriers and a total of 10 million commercial operations were by commuter/air taxi carriers in the United States in 2010.

The total GSE count for the major air carrier group was multiplied by the ratio of total major air carrier operations in the United States divided by the commercial operations for the five air carriers in the airline-provided GSE data sets. This calculation indicated that nationally, major air carriers could potentially account for 47,000 units of GSE.

The total GSE count for the commuter carrier group was multiplied by the ratio of total air taxi operations in the United States divided by the commercial operations for the two commuter carriers in the airline-provided GSE data sets. This calculation indicated that nationally, commuter carriers could potentially account for 27,000 units of GSE.

Overall, the estimate of the national GSE inventory using this approach would be approximately 74,000 units (47,000 plus 27,000). This result is substantially lower than the estimated inventory developed from airport survey data (~108,000). Several possible explanations for the apparent discrepancy are provided in the following paragraphs.

Survey Sample Size. The airport field survey was conducted at airports that were selected to represent the national average. The commercial operations at these airports represented approximately 10 percent of the national commercial operations in 2010. While a 10 percent sample population is not unreasonable for estimating the national inventory, the possibility does exist that the selected airports have substantially higher GSE counts than the national average.

Equipment Ownership. In reviewing the airline-provided GSE data, the research team noted that the GSE owned per operation fluctuated between 1 and 6 total units of equipment per 1,000 commercial operations. The research team assumed that one or more of the airlines outsourced, at least partially, the ground handling activity. If so, the equipment would belong to the ground handler and would not be in the airline data sets. Also, equipment owned by the airports in the field survey database would not be included in the airline data sets. This situation would lead to an underestimate of the national GSE fleet when commercial operations are applied to the airline-provided data to scale up from the sample population data to the national inventory. The researchers reviewed the raw survey forms and determined that approximately 24 percent of the total GSE counted in the field survey was owned by fixed base operators (FBOs), ground handlers, or airport operators. Thus, the national inventory estimated from the airline-provided data could be adjusted upward by this percentage to account for non-airline-owned equipment. Making such an adjustment increases that inventory from approximately 74,000 to 92,000 units of equipment.

Cold Weather Adjustment. The correlation developed from the survey data for total GSE (Equation 8) included an adjustment for cold weather airports that was not applied to the airline data. It was not possible to include a correction for cold weather effects to the airline-provided data, because some of the data provided did not include the airport where the equipment was located. However, the general effect of the adjustment term was to increase the effective operations when calculating GSE, and applying the term provided an improvement in the correlation (increased the coefficient of determination to 0.992 from 0.951). Comparing the terms in Equation 8 for the 500+ airports included in the national inventory, an adjustment of 20 percent was applied to the commercial operations overall to get to the estimated national inventory. Increasing the national GSE inventory estimated from the airline-provided data by 20 percent would result in an inventory of 100,000 units of GSE, within 8 percent of the national inventory estimated from the airport survey correlation. Therefore, the weather adjustment parameter in Equation 8 is at least partially responsible for the differences between the two national inventories.

Potential Outlier Impact. The correlations developed from the field survey data were made with data from 11 of the 12 surveyed airports. As noted in Section 3.6.1, data from DTW was not included due to severe weather hampering data collection efforts during the survey. If these data were included in a correlation based on all 12 surveyed airports, a lower estimate of the national inventory would be determined, because the DTW data point is well below the approximate line between the other airports, as shown in Figure 3-6. However, it is the distance off of this line that indicates the DTW GSE count is an outlier, and the reason for the unusually low count is known. Therefore, the initial correlation developed from the 11 other airports is considered better for predicting the national inventory than a correlation developed with the DTW data.

Potential Electric GSE Impact. Anecdotal evidence suggests that operators of electric GSE may need to provide additional units of equipment compared to combustion-driven equipment due to the charging time necessary for electric GSE. The equipment being charged is essentially

unavailable, and operators need additional equipment to maintain service levels. The surveyed airports all had some quantity of electric GSE. The largest airport surveyed (DFW) had the highest proportion of electric GSE, 26 percent of that airport's fleet. Five other surveyed airports had between 13 and 24 percent electric GSE in their fleets. The average of the surveyed airports was approximately 12 percent electric. If this average value for the surveyed airports is above the national average for electric GSE, and if operators of electric GSE truly need additional equipment, then the national inventory developed from survey data may be overestimated. However, this conclusion does not appear to be consistent with the airline-provided GSE data. The airline-provided data had more electric equipment in the aggregated fleet mix (21 percent), yet the estimate from this information provided a much lower national GSE inventory. It does not appear the differences between the two estimates can be explained by differences in the relative quantity of electric GSE.

3.6.3 Existing GSE Data Sets

Finally, several GSE inventories that had been previously developed for individual airports were obtained and subjected to the correlation developed from the field surveys. The inventories used were for Los Angeles International Airport (2000 and 2006), Seattle-Tacoma International Airport (2002), and the Houston Airport System (1996). Three airports are included in the Houston Airport System (HAS) inventory: George Bush Intercontinental Houston (IAH), Hobby (HOU), and Ellington Field (EFD). The comparison of the inventoried GSE with predicted GSE counts are shown on Figure 3-8.

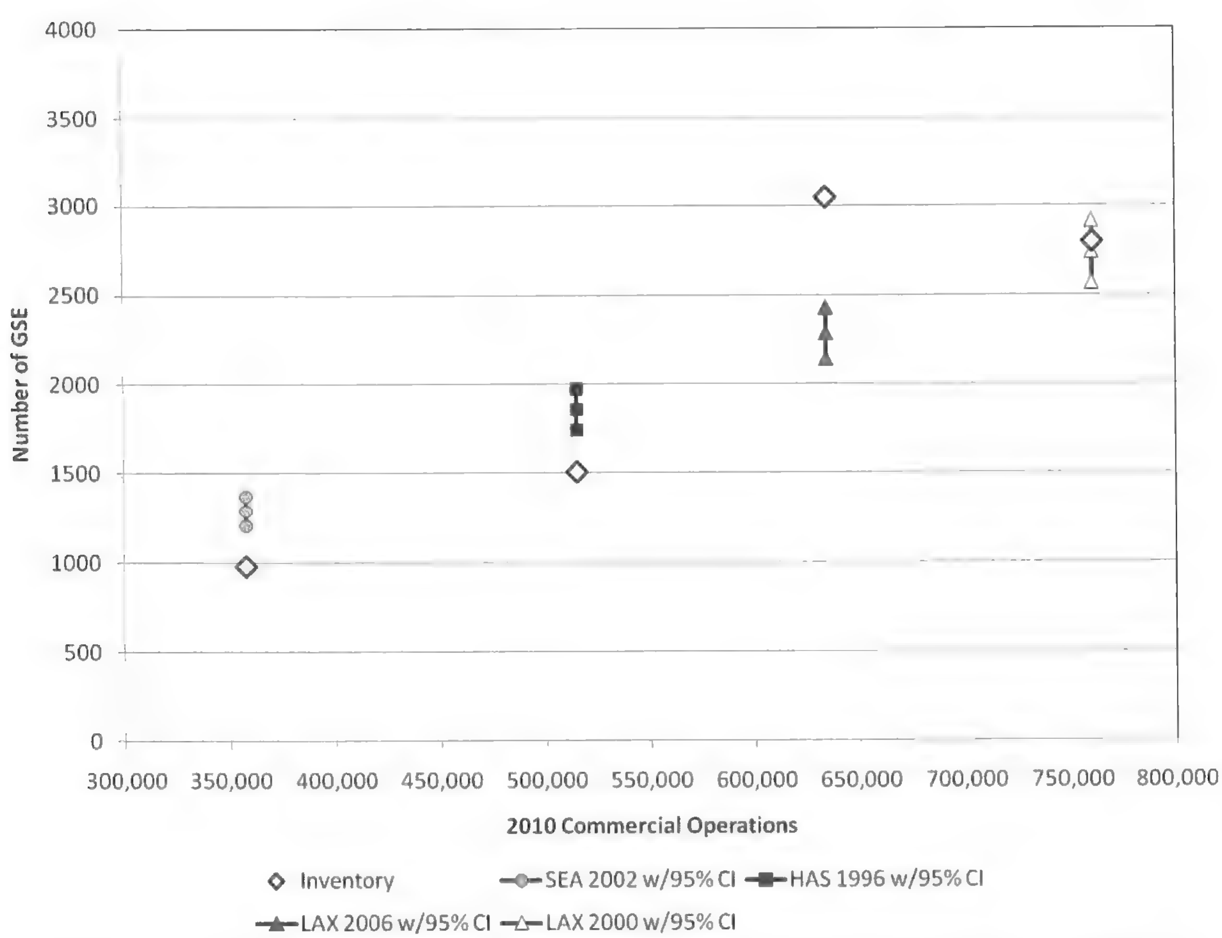


Figure 3-8. GSE inventories for selected airports and years versus predicted values with 95% confidence intervals.

This comparison indicates that the correlation has substantial errors when applied to individual airports. However, note that the total inventory for the airports in this comparison is 8,330 units of equipment, while the predicted total for the same airports is 8,169 units of equipment, an error of less than 2 percent. Therefore, the correlation is considered most appropriate for estimating the national GSE inventory, and possibly large regional inventories. However, using the correlation for individual airports is not recommended.

3.6.4 National GSE Inventory Recommendation

The research team recommends that the national GSE inventory developed from the correlation based on data collected at 11 of the surveyed airports (see Section 3.6.1) be used as the best estimate for the time period of this evaluation. If the estimated inventory developed from airline-provided data is adjusted upward to account for both the non-airline-owned equipment and the cold weather factor, the adjusted inventory would be approximately 110,000 units, very close to the 108,600 value predicted from the survey data correlation.

3.7 Economic Factors

Prepared in connection with Task 8, this element of the Working Plan was designed to provide GSE owners and operators with practical information pertaining to (1) alternative fuels, (2) costs for infrastructure, (3) purchasing vs. retrofit costs, and (4) other qualitative considerations pertaining to operating GSE. For ease of understanding, this information is provided in the following subsections as responses to four questions pertaining to these topics.

3.7.1 Alternative Fuels

What alternative fuels are appropriate and available for GSE equipment types?

Section 3.4 provides a comprehensive assessment of the types of alternative fuels presently available for GSE and, therefore, the information is not repeated here. However, they include the following:

- Mixtures containing 85 percent or greater ethanol (E85)
- Mixtures containing 20 percent or greater biodiesel meeting ASTM D 6751
- Natural gas (compressed or liquefied)
- Liquefied petroleum gas (propane)
- Methanol
- Hydrogen
- Electricity

Each of these fuel types are described in terms of their energy content, availability, costs, infrastructure requirements, and use with GSE. Among them, electric (i.e., battery), propane, and natural gas are presently the most commonly used.

3.7.2 Infrastructure

What is the range of costs for infrastructure for each alternative-fuel type?

The infrastructure requirements for alternative-fuel GSE, as well as their costs, are discussed in Section 3.4. This information addresses the primary needs of (1) fuel tanks and dispensing equipment for CNG and LPG GSE and (2) the electrical charging equipment for electric GSE.

Table 3-22. Summary of VALE projects.

Airport	Project Description	Total Cost	Cost Per Unit
Cincinnati/ Northern Kentucky International Airport	Installation of 16 PCA units	$1,760,000	$110,000
	Installation of 14 gate electrification units	$854,000	$61,000
	Electrical infrastructure upgrades	$625,000	$625,000
Erie International Airport/Tom Ridge Field	Installation of 2 PCA units (20-ton)	$140,000	$70,000
	Installation of 1 PCA unit (30-ton)	$70,000	$70,000
	Electrical infrastructure upgrades	$90,000	$90,000
Gerald R. Ford International Airport	Installation of 3 PCA units (30-ton)	$232,264	$77,421
	Installation of 2 PCA units (75-ton)	$280,222	$140,111
	Installation of 3 ground power units (90 kVA)	$167,311	$55,770
	Installation of 2 ground power units (140 kVA)	$152,884	$76,442
	Electrical infrastructure upgrades	$177,183	$177,183
	Installation of 6 PCA units (30-ton)	$449,904	$74,984
	Installation of 6 ground power units (400 Kz)	$319,392	$53,232
Lehigh Valley International Airport	Installation of 7 PCA units (30-ton)	$872,780	$124,683
	Installation of 1 PCA unit (45-ton)	$148,860	$148,860
	Electrical infrastructure upgrades	$657,099	$657,099
Philadelphia International Airport	Installation of 25 electric GSE rechargers	$2,642,007	$105,680
	Electrical infrastructure upgrade	$5,843,640	$5,843,640
Seattle-Tacoma International Airport	Installation of central PCA 48 gates (Phase I)	$40,600,600	$845,833
	Installation of central PCA 23 gates (Phase II)	$4,816,905	$209,431
University Park Airport	Electric vehicle recharger	$10,327	$10,327

Over the past several years, the FAA VALE Program has financed a number of airport improvements aimed at supporting alternative-fuel GSE or reducing the need for conventional-fuel GSE. Table 3-22 contains a summary listing of several VALE projects designed to meet these objectives.

As shown, the costs for the infrastructure varies widely based upon the type of project, the system capacity, and a wide array of supporting apparatus. For example, the costs for electric GSE recharging stations range from approximately $10,000 to $60,000 according to their size and quantity purchased. By comparison, PCA units, which eliminate the need for GPUs, range in costs from $50,000 to more than $100,000.

3.7.3 Purchasing versus Retrofit

What are the relative costs for purchasing new equipment versus retrofitting existing GSE?

The costs to purchase GSE are among the leading considerations among owners and operators of the equipment when evaluating whether to invest in new, alternative-fuel models or to retrofit existing stock. This aspect of GSE ownership is particularly challenging in times of economic decline and airline mergers—given the significant capital costs required to operate a fleet of equipment. For clarity, capital costs are one-time expenditures incurred when new GSE is purchased.

It is also because of these potentially significant capital expenditures that the purchase cost is difficult to obtain. For example, because most GSE are purchased in multiple units as opposed to individual procurements, the cost for each unit varies based on the size and make-up of the order. This is further compounded by the fact that neither GSE manufacturers nor the GSE purchasers are willing to reveal the details of their transaction for business reasons. These and several other variables that have an effect on the costs of purchasing GSE are addressed in Section 3.4.1.

Table 3-23. Ballpark GSE purchase costs.

Type	Fuel Type	Costs
Ground Power Unit	Diesel	$17,000
Baggage Tractor	Gasoline	$26,000
	Diesel	$28,000
	Electric	$35,500
Belt Loader	Gasoline	$28,500
	Diesel	$32,200
	Electric	$38,800
Pushback Tug	Diesel	$86,200
	Electric	$93,000
Cargo Loader	Diesel	$475,000

Within the public domain of information, the Idaho National Laboratories GSE Cost-Benefit Analysis Study provides a representative and most up-to-date sample of the purchase costs for commonly used GSE. Broken out by three fuel types (i.e., gasoline, diesel, and electric), these "ballpark" costs are listed in Table 3-23.

As shown, conventional-fuel (i.e., gasoline and diesel) baggage tractors and belt loaders range from $26,000 to $32,000 at the small end of the spectrum with the bigger aircraft pushback tugs at $86,000 and the much larger cargo loaders at $475,000. Where the data are available, diesel equipment generally costs 10 to 15 percent more than gasoline, and electric equipment generally costs 10 to 25 percent more than diesel. Moreover, charging stations are additional costs for electric GSE that are not accounted for in the purchase costs.

In some areas of the country, particularly those that are designated as nonattainment for the NAAQS, there is pressure on GSE owners and operators to convert conventional-fuel GSE to alternative-fuel technologies—often before the useful life of the original equipment is reached. In most cases, the gasoline/diesel engines are replaced with electric motors and batteries, and the body, chassis, and drive chain are retained. In the cases of natural gas or propane, the conversions are generally more compatible, and therefore less costly.

As noted previously, purchase costs were difficult to obtain for both new equipment purchases and for retrofitting equipment. In most GSE types, the engine is likely the most expensive item in the GSE purchase price. The cost of converting existing GSE to operate on alternative-fuel engines may be comparable to replacing the engine on the existing gasoline or diesel GSE. Retrofitting costs may also be in the ballpark of purchasing a new GSE, especially if the retrofitting is done on an as-needed or piecemeal basis compared to large lot purchases of new equipment.

3.7.4 Qualitative Considerations

What are the qualitative considerations an airline and airport must take into account concerning operating GSE?

Among the range of qualitative factors that are deemed as potentially significant, the majority have already been identified and discussed in Section 3.4. Therefore, the following provides a synopsis of this material, supplemented with other relevant information, where appropriate.

Safety

Airlines and airports will both agree that among the leading considerations concerning the operation of GSE is that it must be safe to operate. For example, many GSE have various safety design features such as speed restriction mechanisms, safety mirrors, operator enclosures, safety

lights and markings, etc. To achieve equivalent levels of safety among various types of equipment, additional operator training and safety supervision is often required.

The airline and airport also need to consider the safety of infrastructure that would be required for various types of GSE (e.g., operating electric GSE battery charging stations and risks associated with water/weather, electric shock, electric overload, etc.).

The airline and airport may classify safety as both a financial and non-financial consideration because of the additional training, insurance costs, and/or liability that may be associated with the operation of certain GSE.

Environmental

Airlines and airports have shown a renewed interest in business decisions that focus on environmental (i.e., "green") initiatives. For example, many airlines and airports have corporate sustainability policies and/or guidance manuals that encourage or even require decision makers to consider environmental impacts. As such, airline and airport management are cognizant that their business decision may have an effect on the environment. Additionally, environmental cost implications could result from various types of fuel spills and/or accidents that could result in financial penalties, U.S. EPA visits, consulting costs, etc.

Public Perception/Marketing

The general public's awareness and/or perception of an airline's and/or an airport's environmental responsibility may influence the decision to purchase and/or operate alternative-fuel GSE. Airline employees, stockholders, airport employees, customers, local businesses, and the residential community are increasingly aware of management decisions that could harm the environment. Additionally, the press is quick to acknowledge an airline or airport that chooses to operate alternative-fuel GSE instead of conventional-fuel GSE out of its own "goodwill." Airlines and airports also have their own opportunity to self-promote their environmentally responsible decisions. Where competition for airlines or airports is prevalent, some customers may be less inclined to purchase a plane ticket from an airline/airport that has received negative press attention for fuel spills and the operation of high-emitting GSE (for example) compared to an airline or airport that is perceived to be an environmental steward. Therefore, an airline or airport should recognize the value of public perception and marketing opportunities in its decision to operate GSE.

Understanding the attitude of the government and the business community toward the environmental stewardship of an airline or airport may similarly have an influence on purchasing decisions. Outside biases toward airlines or airports may influence non-financial decisions with regard to certain types of GSE operations. The business climate may also nurture future economic trends that could influence GSE decisions contrary to existing economic conditions.

Regulatory Considerations

Certain regulatory requirements influence the decision to purchase and/or operate alternative-fuel GSE. Regulatory requirements may exist at the national, state, and/or local level. Examples of regulatory agencies include the U.S. DOT, FAA, U.S. EPA, and the Occupational Safety and Health Administration. Airlines and airports will need to take into account all pertinent local, state, and federal laws and regulations when considering what type of GSE to operate at the airport. Where the laws and/or regulations are vague, the airline and airport must make a qualitative judgment in the decision-making process.

Weather and Climate

Certain GSE fuel types may have differing efficiencies depending on weather conditions. The airline and airport management need to determine if their airport operating environment is

suitable for the fuel type and GSE being considered. For example, diesel GSE may provide better operating performance than biodiesel GSE in extreme cold weather climates because of potential cold-temperature gelling of biodiesel (without fuel additives). Therefore, some GSE powered by non-conventional fuels may be better suited for warmer weather environments. The airline and airport need to include the expected weather conditions as a qualitative consideration for operating GSE.

GSE Needs

The airline and airport will need to determine the task that needs to be accomplished and the GSE type that would be matched to accomplish that task (e.g., "the right tool for the right job"). The airline and airport do not wish to purchase GSE that underperforms or overperforms but rather matches the GSE specifications to the operational objective. The airline and airport will need to take into consideration the availability of various fuels when evaluating the type of GSE that will be used at the airport.

Acronyms and Abbreviations

ABE—Lehigh Valley International Airport
ACRP—Airport Cooperative Research Program
AC—Alternating Current
ACU—Air Conditioning Unit
AFV—Alternative-Fuel Vehicle
AIP—Airport Improvement Program
ARFF—Aircraft Rescue and Firefighting
As—Arsenic
ASIG—Aircraft Service International Group
ASTM—American Society for Testing and Materials
APU—Auxiliary Power Unit
ASU—Air Start Unit
AT—Air Toxics
ATADS—Air Traffic Activity Data System
ATL—Hartsfield-Jackson Atlanta International Airport
B100—Biodiesel (100 percent)
B20—Biodiesel Blend (20 percent biodiesel, 80 percent petroleum diesel)
B85—Biodiesel Blend (85 percent biodiesel, 15 percent petroleum diesel)
BEV—Battery Electric Vehicle
BHP—Brake Horsepower
BOI—Boise Airport
BOS—Logan International Airport (Boston)
BSFC—Brake-Specific Fuel Consumption
BTU—British Thermal Unit
CAA—Clean Air Act
CARB—California Air Resources Board
CCR—California Code of Regulations
CDM—CDM Smith
CFR—Code of Federal Regulations
CH_4—Methane
CI—Compression Ignition
CNG—Compressed Natural Gas
CO—Carbon Monoxide
CO_2—Carbon Dioxide
CO_{2e}—Carbon Dioxide Equivalents
DC—Direct Current
DERA—Diesel Emissions Reduction Act
DFW—Dallas-Fort Worth International Airport

DME—Dimethyl Ether
DTW—Detroit Metropolitan Wayne County Airport
E85—Ethanol
EDMS—FAA's Emissions and Dispersion Modeling System
EERE—Energy Efficiency and Renewable Energy
EFD—Ellington Field
EGR—Exhaust Gas Recirculation
EPAct—Energy Policy Act
ETMSC—Enhanced Traffic Management System Counts
EV—Electric Vehicle
FAA—Federal Aviation Administration
FAT—Fresno Yosemite International Airport
FBO—Fixed-Based Operator
FCEV—Fuel Cell Electric Vehicle
FFV—Flexible Fuel Vehicle
FOD—Foreign Object Debris
FTG—Front Range Airport (Watkins, Colorado)
GA—General Aviation
GDE—Gallon of Diesel Equivalent
GGE—Gallon of Gasoline Equivalent
GHG—Greenhouse Gas
GPU—Ground Power Unit
GRR—Gerald R. Ford International Airport
GSE—Ground Service Equipment
GWP—Global Warming Potential
H_2—Hydrogen
HAP—Hazardous Air Pollutant
HC—Hydrocarbons
HEV—Hybrid Electric Vehicle
Hg—Mercury
HOU—William P Hobby Airport (Houston)
HPN—Westchester County Airport
IAH—George Bush Intercontinental Airport (Houston)
ICE—Internal Combustion Engine
I/M—Inspection/Maintenance
IND—Indianapolis International Airport
IPCC—Intergovernmental Panel on Climate Change
IRIS—U.S. EPA's Integrated Risk Information System
JFK—John F Kennedy International Airport
kWh—Kilowatt-Hour
LAX—Los Angeles International Airport
LGA—New York LaGuardia Airport
Li-ion—Lithium-Ion
LiM-polymer—Lithium-Metal Polymer
LNG—Liquefied Natural Gas
LPG—Liquefied Petroleum Gas
MHT—Manchester-Boston Regional Airport
Mn—Manganese
MPO—Metropolitan Planning Organization
MSHA—U.S. Department of Labor Mining Safety Health Administration

MSP—Minneapolis-St. Paul International Airport
MTBE—Methyl Tert-Butyl Ether
NAAQS—National Ambient Air Quality Standards
NEC—National Electrical Code
NEV—Neighborhood Electric Vehicle
NG—Natural Gas
Ni-Cd—Nickel-Cadmium
Ni-MH—Nickel-Metal Hydride
NMHC—Non-methane Hydrocarbons
NMOG—Non-methane Organic Gases
N_2O—Nitrous Oxide
NO_2—Nitrogen Dioxide
NO_x—Nitrogen Oxide
NTP—Notice to Proceed
O_3—Ozone
O&M—Operations and Maintenance
OEM—Original Equipment Manufacturer
OBD—On-board Diagnostic
OPSNET—Operations Network
ORD—Chicago O'Hare International Airport
Pb—Lead
PCA—Preconditioned Air
PDX—Portland International Airport
PFC—Passenger Facility Charges
PHL—Philadelphia International Airport
PHX—Phoenix Sky Harbor Airport
PM—Particulate Matter
$PM_{2.5}$—Particulate Matter, aerodynamic diameter of 2.5 micrometers or less
PM_{10}—Particulate Matter, aerodynamic diameter of 10 micrometers or less
SAE—Society of Automotive Engineers
SDF—Louisville International Airport
Se—Selenium
SEA—Seattle-Tacoma International Airport
SI—Spark Ignition
SIP—State Implementation Plan
SJC—Norman Y. Mineta San Jose International Airport
SLC—Salt Lake City International Airport
SMF—Sacramento International Airport
SNA—John Wayne Airport
STL—Lambert-St. Louis International Airport
SO_2—Sulfur Dioxide
TAF—Terminal Area Forecast
THC—Total Hydrocarbons
TIP—Tribal Implementation Plan
TOG—Total Organic Gases
TPA—Tampa International Airport
TRB—Transportation Research Board
TUS—Tucson International Airport
UFP—Ultra-Fine Particles
ULSD—Ultra-Low Sulfur Diesel

UPS—United Parcel Service
USAF—U.S. Air Force
U.S. DOE—U.S. Department of Energy
U.S. EIA—U.S. Energy Information Administration
U.S. EPA—U.S. Environmental Protection Agency
V—Vanadium
VALE—Voluntary Airport Low Emission
VOC—Volatile Organic Compound

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APPENDIX A

List of Available GSE Products

List of Available Products (Sorted by Equipment Type)

Company	Distributor or Manufacturer	Participated in Research Project	Type of Equipment	Model	Fuel Type (Where Specified in Product Literature)	Notes
Tronair	Manufacturer		AC Cart	17-7503-7000		
Tronair	Manufacturer		AC Cart	17-7505-7000	Gasoline	20 hp engine
Carolina Ground Service Equip	Distributor		AC Generator	S&S TM 4900 AC Generator	Diesel	
McDermott Associates Inc	Manufacturer		AC Power Unit	JetMac (multiple models)	Gasoline/ Diesel	
Aero Specialties	Distributor	Yes	Air Conditioner	TLD ACE 302-CUP	Diesel/ Electric	Diesel-electric and utility powered electric air conditioning and heating
Aero Specialties	Distributor	Yes	Air Conditioner	TLD ACU-804-Cup	Diesel	Single connection aircraft
Aviation Ground Equip	Distributor		Air Conditioner	RJ150	Diesel/Jet Fuel	Noted that engines are diesel and jet fuel compatible
FCX Systems	Manufacturer		Air Conditioner	GSAC020	Diesel	Blower: 10 hp
FCX Systems	Manufacturer		Air Conditioner	GSAC030	Diesel	Blower: 15 hp
FCX Systems	Manufacturer		Air Conditioner	GSAC060	Diesel	Blower: 50 hp
FCX Systems	Manufacturer		Air Conditioner	GSAC090	Diesel	Blower: 75 hp
Mercury GSE	Distributor		Air Conditioner	Ace Devtec 804-320	Diesel	
Omega Aviation	Distributor		Air Conditioner	2030DE	Diesel	
Omega Aviation	Distributor		Air Conditioner	2425FD	Diesel	
TLD	Manufacturer		Air Conditioner	ACU-302	Diesel	
TLD	Manufacturer		Air Conditioner	ACU-802		
TLD	Manufacturer		Air Conditioner	ACU-804	Diesel	
TLD	Manufacturer		Air Conditioner	ACU-808	Diesel	
Tug Technologies	Manufacturer	Yes	Air Conditioner	AC20E	Electric	
Tug Technologies	Manufacturer	Yes	Air Conditioner	ACU500		Engine hp is 385, blower hp is 75, compressor hp 200
Victory GSE	Distributor	Yes	Air Conditioner	MA-3D	JP4/JP5/JP8/ DF1/DF2/Jet A/ Jet A1/Jet 8	
Jetall	Distributor		Air Start Unit	Libby A/MA1A		
Jetall	Distributor		Air Start Unit	Allied Signal AS 120	Jet Fuel/ JP4	
Jetall	Distributor		Air Start Unit	Jetall JTL 180 Twin Pack		
Mercury GSE	Distributor		Air Start Unit	TLD 270 PPM		
Mercury GSE	Distributor		Air Start Unit	TMD-250 PPM		
Tronair	Manufacturer		Air Start Unit	SA28D2	Diesel	
Tronair	Manufacturer		Air Start Unit	SA280G2	Gasoline	
Tronair	Manufacturer		Air Start Unit	SA500D2	Diesel	
Tronair	Manufacturer		Air Start Unit	SA500G2	Gasoline	
Tug Technologies	Manufacturer	Yes	Air Start Unit	TMD/TRD-150/180	Diesel	425-500 hp depending on the engine manufacturer (Detroit diesel or Cummins diesel)
Tug Technologies	Manufacturer	Yes	Air Start Unit	TMD/TRD-250	Diesel	Detroit diesel engine is 630 hp, Cummins engine is 600 hp
Tug Technologies	Manufacturer	Yes	Air Start Unit	TMD/TRD-400	Diesel	905 bhp - Detroit diesel engine
Omega Aviation	Distributor		Air Start Unit	TMAC-170	Diesel	
Omega Aviation	Distributor		Air Start Unit	TMAC135	Detroit Diesel	V-8 engine, 135 PPM

List of Available Products (Sorted by Equipment Type)

Company	Distributor or Manufacturer	Participated in Research Project	Type of Equipment	Model	Fuel Type (Where Specified in Product Literature)	Notes
Davin Inc	Distributor		Air Start Unit	Trilectron Model PSC1800	Diesel	
Red Box International	Distributor (refurbished)		Aircraft Lifting	AirLift		
Davin Inc	Distributor (used)		Aircraft Tow Tractor	JBT Model B1200	Diesel	
Davin Inc	Distributor (used)		Aircraft Tow Tractor	NMC-Wollard Model 140 (A/S32A-42)	Diesel	
Davin Inc	Distributor (used)		Aircraft Tow Tractor	S&S Model MB-2 (GT-40)	Diesel	
Davin Inc	Distributor (used)		Aircraft Tow Tractor	SML-80-D	Diesel	
Davin Inc	Distributor (used)		Aircraft Tow Tractor	Grove Model MB-2	Diesel	
Davin Inc	Distributor (used)		Aircraft Tow Tractor	NMC-Wollard Model 1212G	Gasoline	
JBT AeroTech	Manufacturer		Aircraft Tow Tractor	B400	Diesel	100 hp
JBT AeroTech	Manufacturer		Aircraft Tow Tractor	B1200	Diesel	290 hp
JBT AeroTech	Manufacturer		Aircraft Tow Tractor	B600		
Lektro	Manufacturer		Aircraft Tow Tractor	AP8600A		6.8 hp
Lektro	Manufacturer		Aircraft Tow Tractor	AP8600A-EZ		6.8 hp
Lektro	Manufacturer		Aircraft Tow Tractor	AP8700C-EZ	Electric	
Lektro	Manufacturer		Aircraft Tow Tractor	AP8700C	Electric	
Lektro	Manufacturer		Aircraft Tow Tractor	AP8700CX	Electric	
Lektro	Manufacturer		Aircraft Tow Tractor	AP8700CX-EZ	Electric	
Lektro	Manufacturer		Aircraft Tow Tractor	AP8750C-EZ	Electric	
Lektro	Manufacturer		Aircraft Tow Tractor	AP8750C	Electric	
Lektro	Manufacturer		Aircraft Tow Tractor	AP8750C-AL-700	Electric	
Lektro	Manufacturer		Aircraft Tow Tractor	AP8750CX	Electric	
Lektro	Manufacturer		Aircraft Tow Tractor	AP8750CX-EZ	Electric	
Lektro	Manufacturer		Aircraft Tow Tractor	AP8750CX-AL	Electric	
Lektro	Manufacturer		Aircraft Tow Tractor	AP8700CX-EZ	Electric	
Lektro	Manufacturer		Aircraft Tow Tractor	AP7850CX-AL	Electric	
Lektro	Manufacturer		Aircraft Tow Tractor	AP8800SDA-EZ	Electric	
Lektro	Manufacturer		Aircraft Tow Tractor	AP8800SDA	Electric	
Lektro	Manufacturer		Aircraft Tow Tractor	AP8850SDA-AL-100	Electric	
Lektro	Manufacturer		Aircraft Tow Tractor	AP8900SD	Electric	
Lektro	Manufacturer		Aircraft Tow Tractor	AP8950SD	Electric	
Aero Specialties	Distributor	Yes	Aircraft Tow Tractor	Eagle TT Series	Diesel	Tier 3
Aero Specialties	Distributor	Yes	Aircraft Tow Tractor	TT - 4	Gasoline/ Diesel	Optional fuel types - 16 gallon tank
Aero Specialties	Distributor	Yes	Aircraft Tow Tractor	TT - 5	Gasoline/ Diesel	Optional fuel types - 16 gallon tank
Aero Specialties	Distributor	Yes	Aircraft Tow Tractor	TT - 6	Gasoline/ Diesel	
Aero Specialties	Distributor	Yes	Aircraft Tow Tractor	TT - 8 AWD	Gasoline/ Diesel	All wheel drive for military aircraft
Aero Specialties	Distributor	Yes	Aircraft Tow Tractor	Eagle eTT - 8	Electric	AWD/All Wheel Steer
Aero Specialties	Distributor	Yes	Aircraft Tow Tractor	Eagle TT - 10 AWD	Diesel	4 cyl turbo Tier III
Aero Specialties	Distributor	Yes	Aircraft Tow Tractor	Eagle TT - 12 AWD	Diesel	
Aero Specialties	Distributor	Yes	Aircraft Tow Tractor	Eagle eTT - 12	Electric	AWD/All Wheel Steer
Goldhofer	Manufacturer		Aircraft Tow Tractor	AST-1 X		490 hp , 680 hp, 1360 hp available - many different, similar versions
Goldhofer	Manufacturer		Aircraft Tow Tractor	AST-2		Many options available
Goldhofer	Manufacturer		Aircraft Tow Tractor	AST-3 F/L		Many options available
TLD	Manufacturer		Aircraft Tow Tractor	TPX-200		
TLD	Manufacturer		Aircraft Tow Tractor	TPX-200-S		
TLD	Manufacturer		Aircraft Tow Tractor	TPX-200 MT		
TLD	Manufacturer		Aircraft Tow Tractor	TPX-100E	Electric	
TLD	Manufacturer		Aircraft Tow Tractor	TPX-500		
TLD	Manufacturer		Aircraft Tow Tractor	TPX-500-S		
TLD	Manufacturer		Aircraft Tow Tractor	TPX-500 MTS		Electrically controlled GPU is an option
TLD	Manufacturer		Aircraft Tow Tractor	TPX-200 MTS		
Carolina Ground Service Equip	Distributor		Aircraft Tow Tractor	Lektro AP-8750-B	Electric	Used 2002
Carolina Ground Service Equip	Distributor		Aircraft Tow Tractor	Jetporter JP75	Electric	Used 2008 - two 8 hp motors

List of Available Products (Sorted by Equipment Type)

Company	Distributor or Manufacturer	Participated in Research Project	Type of Equipment	Model	Fuel Type (Where Specified in Product Literature)	Notes
Carolina Ground Service Equip	Distributor		Aircraft Tow Tractor	A&G Mercury 830-V6E	Gasoline	Ford 4.2 Liter V-6
Carolina Ground Service Equip	Distributor		Aircraft Tow Tractor	JP100S		Two 10 hp continuous duty drive motors
Carolina Ground Service Equip	Distributor		Aircraft Tow Tractor	Jetporter JP30	Electric	
Carolina Ground Service Equip	Distributor		Aircraft Tow Tractor	Jetporter JP30L	Electric	
Tug Technologies	Manufacturer	Yes	Aircraft Tow Tractor	GT35E	Electric	45 hp Motor
Tug Technologies	Manufacturer	Yes	Aircraft Tow Tractor	TUG GT35	Diesel/Jet A/JP-8	88.4 hp
Tug Technologies	Manufacturer	Yes	Aircraft Tow Tractor	TUG GT50	Diesel/Jet A	169 hp
Tug Technologies	Manufacturer`	Yes	Aircraft Tow Tractor	U30	Diesel/Jet A	268 hp
Charlatte America	Manufacturer	Yes	Aircraft Tow Tractor	CPB35E	Electric	35 hp
Omega Aviation	Distributor		Aircraft Tow Tractor	Hough T-300	Diesel	
Omega Aviation	Distributor		Aircraft Tow Tractor	Aero Tug TD-30	Diesel	
Omega Aviation	Distributor		Aircraft Tow Tractor	Harlan CT-120	Gasoline	
Omega Aviation	Distributor		Aircraft Tow Tractor	Tug MC-22-4	Diesel	
Aero Specialties	Distributor	Yes	Aircraft Tow Tractor	Eagle MTT	Electric	
Aero Specialties	Distributor	Yes	Aircraft Tow Tractor	AERO Specialities Tug Inc M1A	Gasoline/ Diesel/JetA	
Aero Specialties	Distributor	Yes	Aircraft Tow Tractor	Model GT35	Gasoline, No. 2 Diesel, Jet A	
Aero Specialties	Distributor	Yes	Aircraft Tow Tractor	Model GT50	Gasoline, No. 2 Diesel, Jet A	
Aero Specialties	Distributor	Yes	Aircraft Tow Tractor	Model GT110	Gasoline, No. 2 Diesel, Jet A	
Eagle Tugs	Manufacturer		Aircraft Tow Tractor	Eagle MTT	Electric	40 hp
Eagle Tugs	Manufacturer		Aircraft Tow Tractor	EB2-5	Gasoline, Diesel	300 hp gasoline engine, 350 hp diesel engine
Eagle Tugs	Manufacturer		Aircraft Tow Tractor	EB2-6	Gasoline, Diesel	362 hp gasoline engine, 350 hp diesel engine
Eagle Tugs	Manufacturer		Aircraft Tow Tractor	EB2-8	Gasoline, Diesel	362 hp gasoline engine, 350 hp diesel engine
Eagle Tugs	Manufacturer		Aircraft Tow Tractor	EB2-10	Diesel	230 hp engine
Global Ground Support	Manufacturer	Yes	Aircraft Tow Tractor	Model 350	Gasoline	Diesel fuel is an option
Global Ground Support	Manufacturer	Yes	Aircraft Tow Tractor	Model 450	Diesel	Gasoline fuel is an option
Mercury GSE	Distributor		Aircraft Tow Tractor	EGT 38		
Mercury GSE	Distributor		Aircraft Tow Tractor	Paymover T-500		
Mercury GSE	Distributor		Aircraft Tow Tractor	Wollard 1008 Tow Tractor	Diesel/ Gasoline	
TLD	Manufacturer		Aircraft Tow Tractor	JST-Series		"multiple engine packages to meet various environmental conditions"
TLD	Manufacturer		Aircraft Tow Tractor	TMX-400		
TLD	Manufacturer		Aircraft Tow Tractor	TMX-350		
TLD	Manufacturer		Aircraft Tow Tractor	TMX-150		
TLD	Manufacturer		Aircraft Tow Tractor	TMX-450		
TLD	Manufacturer		Aircraft Tow Tractor	TMX-250		
Tronair	Manufacturer		Aircraft Tow Tractor	ET20	Electric	
Tronair	Manufacturer		Aircraft Tow Tractor	ET30	Electric	
Tug Technologies	Manufacturer	Yes	Aircraft Tow Tractor	MRTT	Diesel	
Volk	Manufacturer		Aircraft Tow Tractor	EFZ 80 N	Electric	Two 80 volt three-phase asynchronous motors
Volk	Manufacturer		Aircraft Tow Tractor	EFZ 60 N	Eletric	80 volt three-phase asynchronous motor
Volk	Manufacturer		Aircraft Tow Tractor	EFZ 50 N	Electric	80 volt three-phase asynchronous motor

List of Available Products (Sorted by Equipment Type)

Company	Distributor or Manufacturer	Participated in Research Project	Type of Equipment	Model	Fuel Type (Where Specified in Product Literature)	Notes
Volk	Manufacturer		Aircraft Tow Tractor	EFZ 40 N	Electric	80 volt three-phase asynchronous motor
Volk	Manufacturer		Aircraft Tow Tractor	EFZ 30 N	Electric	80 volt three-phase asynchronous motor
Volk	Manufacturer		Aircraft Tow Tractor	EFZ 30 K	Electric	80 volt three-phase asynchronous motor
Volk	Manufacturer		Aircraft Tow Tractor	EFZ 25 N	Electric	80 volt three-phase asynchronous motor
Volk	Manufacturer		Aircraft Tow Tractor	EFZ 20 N	Electric	80 volt three-phase asynchronous motor
Volk	Manufacturer		Aircraft Tow Tractor	EFZ 20 K	Electric	Two 48 volt three-phase asynchronous motors
Volk	Manufacturer		Aircraft Tow Tractor	EFZ 12 K	Electric	24 volt or 48 volt three-phase asynchronous motor
Volk	Manufacturer		Aircraft Tow Tractor	EFZ 10 K	Electric	24 volt or 48 volt three-phase asynchronous motor
Volk	Manufacturer		Aircraft Tow Tractor	EFZ 8 K	Electric	24 volt or 48 volt three-phase asynchronous motor
Volk	Manufacturer		Aircraft Tow Tractor	EFZ 6 K	Electric	24 volt or 48 volt three-phase asynchronous motor
Volk	Manufacturer		Aircraft Tow Tractor	EFZ 3.5 K	Electric	24 volt or 48 volt three-phase asynchronous motor
Volk	Manufacturer		Aircraft Tow Tractor	EFZ 1.5 K	Electric	24 Volt three-phase asynchronous motor
Volk	Manufacturer		Aircraft Tow Tractor	DFZ 150 H	Diesel	Engine Model Perkins 1104D-E44TA
Volk	Manufacturer		Aircraft Tow Tractor	DFZ 120 H	Diesel	Engine Model Perkins 1104D-E44TA
Volk	Manufacturer		Aircraft Tow Tractor	DFZ 100 H	Diesel	Engine Model Perkins 1104C-44T
Volk	Manufacturer		Aircraft Tow Tractor	DFZ 80 H	Diesel	Engine Model Perkins 1104C-44T
Volk	Manufacturer		Aircraft Tow Tractor	DFZ 60 H	Diesel	Engine Model Perkins 404C-22T
Volk	Manufacturer		Aircraft Tow Tractor	DFZ 50 N	Diesel	Engine Model Perkins 404C-22T or John Deere 4024TF270
Volk	Manufacturer		Aircraft Tow Tractor	DFZ 50 H	Diesel	Engine Model Perkins 404C-22T or John Deere 4024TF270
Volk	Manufacturer		Aircraft Tow Tractor	DFZ 40 N	Diesel	
Volk	Manufacturer		Aircraft Tow Tractor	DFZ 40 H	Diesel	Engine Model Perkins 404C-22T or John Deere 4024TF270
Volk	Manufacturer		Aircraft Tow Tractor	DFZ 30 N	Diesel	
Volk	Manufacturer		Aircraft Tow Tractor	DFZ 30 H	Diesel	Engine Model 404C-22T
Volk	Manufacturer		Aircraft Tow Tractor	DFZ 20 N	Diesel	
Volk	Manufacturer		Aircraft Tow Tractor	DFZ 20 H	Diesel	Engine Model 404C-22T
Volk	Manufacturer		Aircraft Tow Tractor	TFZ 30 N	LPG	VW ADF
Volk	Manufacturer		Aircraft Tow Tractor	TFZ 20 N	LPG	VW ADF
Volk	Manufacturer		Aircraft Tow Tractor	HFZ 40 N	Diesel - Hybrid	Engine is three-phase asynchronous (AC)
Volk	Manufacturer		Aircraft Tow Tractor	HFZ 30 NT	Diesel - Hybrid	Engine is three-phase asynchronous (AC)
Volk	Manufacturer		Aircraft Tow Tractor	HFZ 20 N	Diesel - Hybrid	Engine is three-phase asynchronous (AC)
Ground Support Specialists LLC	Manufacturer		Aircraft Tow Tractor	GS 500		97 hp
Davin Inc	Distributor		Aircraft Tow Tractor	NMC-Wollard Model 6005	Diesel	
Davin Inc	Distributor		Aircraft Tow Tractor	Model 02-2TG-25	Gasoline	
Davin Inc	Distributor		Aircraft Tow Tractor	Model MA-50	Gasoline	
Davin Inc	Distributor		Aircraft Tow Tractor	Model MA-30-1LP	Gasoline	
Davin Inc	Distributor		Aircraft Tow Tractor	Harlan Model HTAJ-50	Gasoline	
Davin Inc	Distributor		Aircraft Tow Tractor	Harlan Model HTAB-40	Diesel	
Harlan Global Manufacturing LLC	Manufacturer		Aircraft Tow Tractor	Charger HLE		42 hp
Harlan Global Manufacturing LLC	Manufacturer		Aircraft Tow Tractor	HTA30/HTA40/HTA50/HTA60	Diesel/ Gasoline/ LPG	
Harlan Global Manufacturing LLC	Manufacturer		Aircraft Tow Tractor	Cargomaster CTA80/HTA100	Diesel/ Gasoline	
Harlan Global Manufacturing LLC	Manufacturer		Aircraft Tow Tractor	Streamline HTLP40/HTLP50/HTLP60	Diesel/ Gasoline/ LPG	

List of Available Products (Sorted by Equipment Type)

Company	Distributor or Manufacturer	Participated in Research Project	Type of Equipment	Model	Fuel Type (Where Specified in Product Literature)	Notes
Harlan Global Manufacturing LLC	Manufacturer		Aircraft Tow Tractor	Streamline HTLP80	Diesel/ Gasoline	
Harlan Global Manufacturing LLC	Manufacturer		Aircraft Tow Tractor	Hercules HTWQSB140/HTWQSB160/HTWQSB180/HTWQS200	Diesel	
Fricke	Distributor (used)		Aircraft Tow/Pushback Tractors	GHH AM150	Diesel	
Fricke	Distributor (used)		Aircraft Tow/Pushback Tractors	GHH AM110	Diesel	
Fricke	Distributor (used)		Aircraft Tow/Pushback Tractors	Schopf F246	Diesel	
Fricke	Distributor (used)		Aircraft Tow/Pushback Tractors	Schopf F106	Diesel	
Harlan Global Manufacturing LLC	Manufacturer		All Purpose Vehicle	HAPV40/HAPV50	Diesel/ Gasoline/ LPG	
Carolina Ground Service Equip	Distributor		Baggage Tug	MA50-1FC	Gasoline	Used 1994
Carolina Ground Service Equip	Distributor		Baggage Tug	A&G Mercury 830-V6E	Gasoline	
Carolina Ground Service Equip	Distributor		Baggage Tug	Clark DT-25 Tug	Diesel	4 cyl engine
Carolina Ground Service Equip	Distributor		Baggage Tug	Elgin ET-3000	Electric	
Carolina Ground Service Equip	Distributor		Baggage Tug	NMC Wollard JG-75	Gasoline	V-8 gasoline engine
Carolina Ground Service Equip	Distributor		Baggage Tug	NMC Wollard 6003-D	Diesel	4 cyl diesel engine
Carolina Ground Service Equip	Distributor		Baggage Tug	MG-30	Gasoline	4 cyl engine
Davin Inc	Distributor		Baggage Tug	S&S Model GT-35	Diesel	
Eagle Tugs	Manufacturer		Baggage Tug	TT-4, TT-5, TT-6, TT-8	Gasoline, Diesel, LPG	80 hp for gasoline or LPG, 68 hp for diesel
Eagle Tugs	Manufacturer		Baggage Tug	TT-10, TT-12	Diesel	Engine is 84 hp
Eagle Tugs	Manufacturer		Baggage Tug	eTT-8	Electric	80V A/C electric drive, 36.7 hp
Eagle Tugs	Manufacturer		Baggage Tug	eTT-12	Electric	80V A/C electric drive, 55 hp
Jetall	Distributor		Baggage Tug	Northwestern JG40-PT16	Gasoline	
Mercury GSE	Distributor		Baggage Tug	MT120	Diesel	
Red Box International	Distributor (refurbished)		Baggage Tug	701	Electric	
Red Box International	Distributor (refurbished)		Baggage Tug	703	Gasoline	
Red Box International	Distributor (refurbished)		Baggage Tug	707	Gasoline	
Red Box International	Distributor (refurbished)		Baggage Tug	709	Gasoline	Liquid propane fuel system optional (Model 709L)
Red Box International	Distributor (refurbished)		Baggage Tug	717	Gasoline	Liquid propane fuel system optional (Model 717L)
Red Box International	Distributor (refurbished)		Baggage Tug	727	Gasoline	Liquid propane fuel system optional (Model 727L)
Red Box International	Distributor (refurbished)		Baggage Tug	737	Gasoline	Liquid propane fuel system optional (Model 727L)
Red Box International	Distributor (refurbished)		Baggage Tug	747 & 747FBO	Gasoline	Liquid propane fuel system optional (Model 747L)
Red Box International	Distributor (refurbished)		Baggage Tug	757 & 757FBO	Gasoline	Liquid propane fuel system optional (Model 757L)
Tronair	Manufacturer		Baggage Tug	JP30	Electric	6 hp 48 v continuous duty motor; the JP30L model has a dual battery pack
Tronair	Manufacturer		Baggage Tug	JP75	Electric	Two 8 hp continuous duty motors and sixteen 6 volt batteries
Tronair	Manufacturer		Baggage Tug	JP100		
Tronair	Manufacturer		Baggage Tug	JP100S	Electric	Two heavy-duty 10 hp motors
Tronair	Manufacturer		Baggage Tug	JP75SC	Electric	Two 8 hp continuous duty motors
Charlatte America	Manufacturer	Yes	Baggage Tug/Tractor	CFB2000	Electric	40 hp
Charlatte America	Manufacturer	Yes	Baggage Tug/Tractor	T-137	Electric	40 hp

List of Available Products (Sorted by Equipment Type)

Company	Distributor or Manufacturer	Participated in Research Project	Type of Equipment	Model	Fuel Type (Where Specified in Product Literature)	Notes
Mercury GSE	Distributor		Baggage Tug/Tractor	TD25	Diesel	
Omega Aviation	Distributor		Baggage Tug/Tractor	TD-23	Diesel	
Omega Aviation	Distributor		Baggage Tug/Tractor	Clark CT-30	Gasoline/ Diesel	
Omega Aviation	Distributor		Baggage Tug/Tractor	Clark CT-40	Diesel	Ford gasoline engine or Perkins diesel
Omega Aviation	Distributor		Baggage Tug/Tractor	TD25	Diesel	
Omega Aviation	Distributor		Baggage Tug/Tractor	DT-025	Diesel	
TLD	Manufacturer		Baggage Tug/Tractor	JET-16	Electric	
Tug Technologies	Manufacturer	Yes	Baggage Tug/Tractor	Tug Model MA	Gasoline/ Diesel/Jet A	There are three optional engine types
Tug Technologies	Manufacturer	Yes	Baggage Tug/Tractor	Tug Model M1A	Gasoline/ Diesel/Jet A	There are three optional engine types
Tug Technologies	Manufacturer	Yes	Baggage Tug/Tractor	MZ	Electric	24 hp continuous or 40 hp peak
Victory GSE	Distributor	Yes	Baggage Tug/Tractor	CTAE-40	Diesel	
Jetall	Distributor		Baggage Tug/Tractor	Clark CT30G	Gasoline	
Jetall	Distributor		Baggage Tug/Tractor	Clark CT40	Gasoline	
Jetall	Distributor		Baggage Tug/Tractor	Clark CT50D	Diesel	
Aeroservicios	Distributor		Baggage Tug/Tractor, Catering Trucks, Deicers, Forklifts, GPUs etc.			New and refurbished GSE - They have a list of what they offer but no specific specs on specific equipment
Phoenix Metal Products Inc	Manufacturer		Belt Loader	Phoenix MBL	Gasoline/ Diesel	Three engines optional Deutz diesel F4M2011 3.1L, GMC gasoline VORTEC 3000 3.4 L, Perkins diesel 1104C 4.4L
Aero Specialties	Distributor	Yes	Belt Loader	TUG Technologies 440E	Electric	Elimination of emissions
Aero Specialties	Distributor	Yes	Belt Loader	TUG Technologies 660	Gas, Diesel, Electric	Perkins or Deutz diesel engine, or Ford 300 gas engine
Aero Specialties	Distributor	Yes	Belt Loader	TUG Technologies 660-27	Gas, Diesel, Electric	Ford 2.3L fuel injected gas engine: Tier 2 compliant
Aero Specialties	Distributor	Yes	Belt Loader	Wasp A2744D	Gasoline/ Diesel	Kohler 18 gasoline engine, diesel engine optional
Charlatte America	Manufacturer	Yes	Belt Loader	CBL100E	Electric	Motor 9 hp/ belt drive motor 1.5 hp
Charlatte America	Manufacturer	Yes	Belt Loader	CBL150E	Electric	Traction motor 5 hp / belt drive motor 1.5 hp
Charlatte America	Manufacturer	Yes	Belt Loader	CBL150D	Diesel	3 cyl
Charlatte America	Manufacturer	Yes	Belt Loader	CBL2000E	Electric	40 hp
Charlatte America	Manufacturer	Yes	Belt Loader	CBL2000D	Diesel	
Cochran Airport Enterprise	Manufacturer		Belt Loader			
Davin Inc	Distributor		Belt Loader	Model TC-888	Diesel	
Davin Inc	Distributor		Belt Loader	NMC Wollard Model TC-886D	Diesel	
Davin Inc	Distributor		Belt Loader	Model 660	Gasoline	Ford 300 6-cyl engine
Jetall	Distributor		Belt Loader	Cochran 606	Gasoline	
Jetall	Distributor		Belt Loader	WASP A1771D		
Jetall	Distributor		Belt Loader	Nordco 2181	Gasoline	
KCI	Manufacturer	Yes	Belt Loader	JBL 16, 20, 24		
Mercury GSE	Distributor		Belt Loader	TUG 660		
Nordco			Belt Loader			
Omega Aviation	Distributor		Belt Loader	TC-886	Diesel	
Omega Aviation	Distributor		Belt Loader	Cargo King	Gasoline	
Omega Aviation	Distributor		Belt Loader	Nordco 4498-3D	Diesel	
TLD	Manufacturer		Belt Loader	NBL		Different engine options
TLD	Manufacturer		Belt Loader	NBL-E		
Tug Technologies	Manufacturer	Yes	Belt Loader	660	Gasoline/ Diesel/Jet A	There are three optional engine types
Tug Technologies	Manufacturer	Yes	Belt Loader	660E	Electric	
Tug Technologies	Manufacturer	Yes	Belt Loader	440E	Electric	
Wasp	Manufacturer		Belt Loader	Kohler Command 18	Gasoline/ Diesel	Standard gasoline engine but diesel engine is optional

List of Available Products (Sorted by Equipment Type)

Company	Distributor or Manufacturer	Participated in Research Project	Type of Equipment	Model	Fuel Type (Where Specified in Product Literature)	Notes
TLD	Manufacturer		Bus	AB-120		Carries 140 passengers within an airport apron area
TLD	Manufacturer		Bus	AB-100		Carries 108 passengers within an airport apron area
TLD	Manufacturer		Cabin Service Vehicle			
TLD	Manufacturer		Cabin Service Vehicle	DT-5004		
Ground Support Specialists LLC	Manufacturer		Cabin Service Vehicle	GS 452		61 hp
Davin Inc	Distributor		Cabin Service Vehicle/Catering Truck	Model HM 18x22 High Lift Truck	Diesel	
Tug Technologies	Manufacturer	Yes	Cargo and Aircraft Tow Tractor	MR-10	Diesel/ Jet 1-A	
JBT AeroTech	Manufacturer		Cargo Loader	Commander 15i	Diesel	110 hp
JBT AeroTech	Manufacturer		Cargo Loader	Commander 15i Electric	Electric	160 V electric system
JBT AeroTech	Manufacturer		Cargo Loader	Commander 30i	Diesel	138 hp (Alternate engine option is Cummins 160 hp)
JBT AeroTech	Manufacturer		Cargo Loader	Commander 40i	Diesel	138 hp
JBT AeroTech	Manufacturer		Cargo Loader	Commander 60i	Diesel	173 hp
JBT AeroTech	Manufacturer		Cargo Loader	RampSnake		
Jetall	Distributor		Cargo Loader	FMC JC/PL-2	Diesel	
Jetall	Distributor		Cargo Loader	Lantis-Cochran 755	Diesel	
Mercury GSE	Distributor		Cargo Loader	FMC Commander 15 Wide		
Mercury GSE	Distributor		Cargo Loader	Lantis 818-144		
Omega Aviation	Distributor		Cargo Loader	Lantis 818-144	Gasoline	
Omega Aviation	Distributor		Cargo Loader	FMC JCPL-1	Gasoline	
Aero Specialties	Distributor	Yes	Cargo Tractor (Bob Tail)	Eagle Tugs EB-2	Gasoline/ Diesel	
Aero Specialties	Distributor	Yes	Cargo Tractor (Bob Tail)	Eagle Tugs F4500	Gasoline/ Diesel	
Aero Specialties	Distributor	Yes	Cargo Tractor (Bob Tail)	Eagle Tugs F5500	Diesel	
Aero Specialties	Distributor	Yes	Cargo Tractor (Bob Tail)	Eagle Tugs F5500	Diesel	More tow capacity and drawbar rating than above option
Aero Specialties	Distributor	Yes	Cargo Tractor (Bob Tail)	Eagle Tugs F6500	Diesel	
Aero Specialties	Distributor	Yes	Cargo Tractor (Bob Tail)	Eagle Tugs F7500	Diesel	
Davin Inc	Distributor		Cargo Tractor (Bob Tail)	Model MPT-546	Gasoline	
Davin Inc	Distributor		Cargo Tractor (Bob Tail)	Model F6000	Diesel	
Aero Specialties	Distributor	Yes	Cleaning Cart	Aero Specialties RJ2Q		Honda generator on board
Hobart	Manufacturer		Compensator	400 Hz Line Drop	Electric	
Omega Aviation	Distributor		Compressor	SAS2000D	Diesel	
Aero Specialties	Distributor	Yes	Container Loader	Used Cochran CL7000-1	Diesel	
JBT AeroTech	Manufacturer		Container Loader	CL-8		84 hp engine - the Perkins 110 4D 44T (I think it's diesel)
Hobart	Manufacturer		Converter	PoWerMaster EV (7.5/15 kVA)	Electric	
Hobart	Manufacturer		Converter	PoWerMaster EV (30/45 kVA)	Electric	
Hobart	Manufacturer		Converter	PoWerMaster EV (60/90 kVA)	Electric	
Hobart	Manufacturer		Converter	PoWerMaster EV (120/150/180 kVA)	Electric	
Hobart	Manufacturer		Converter	PoWerMaster ADV	Eletric	
Fortbrand Services Inc	Distributor		Conveyor Belt Vehicle	MDF12	Diesel	50 hp
Fricke	Distributor (used)		Conveyor Belt Vehicle	EINSA CDA	Diesel	
Global Ground Support	Manufacturer	Yes	Decontamination System	GL-1800D	Diesel, JP-8, Jet A	
Carolina Ground Service Equip	Distributor		Deicer	Trump DD-1200	Gasoline	Engine: 370cid
Carolina Ground Service Equip	Distributor		Deicer	TD-300	Gasoline	Engine: Honda 8 hp
Davin Inc	Distributor		Deicer	SDI Superior Model C2045	Diesel	
Davin Inc	Distributor		Deicer	Trump Model D240		
Ground Support Specialists LLC	Manufacturer		Deicer	GS 700	Diesel	
Ground Support Specialists LLC	Manufacturer		Deicer	GS 1400	Diesel	
Ground Support Specialists LLC	Manufacturer		Deicer	GS 800	Diesel	

List of Available Products (Sorted by Equipment Type)

Company	Distributor or Manufacturer	Participated in Research Project	Type of Equipment	Model	Fuel Type (Where Specified in Product Literature)	Notes
Ground Support Specialists LLC	Manufacturer		Deicer	GS 1200	Diesel	
JBT AeroTech	Manufacturer		Deicer	Tempest		
Jetall	Distributor		Deicer	Trump DD1200		
Jetall	Distributor		Deicer	Trump D40-2		
Omega Aviation	Distributor		Deicer	Trump D40-D	Gasoline	
Omega Aviation	Distributor		Deicer	Trump DD-1200	Gasoline	
Omega Aviation	Distributor		Deicer	Trump TD-30	Gasoline	
Omega Aviation	Distributor		Deicer	Trump D-40-D	Gasoline	
Omega Aviation	Distributor		Deicer	Trump DD	Gasoline	
Omega Aviation	Distributor		Deicer	LA-1000	Gasoline	
Omega Aviation	Distributor		Deicer	Stinar DI-700	Gasoline	
Premier Engineering and Manufacturing	Manufacturer		Deicer	HC29050-G	Gasoline	Auxiliary Power - Honda 13 hp, heating system is Jet A or diesel fired burner
Premier Engineering and Manufacturing	Manufacturer		Deicer	MT43P21 & MT43P21-E	Diesel	Heating system is Jet A or diesel compatible
Premier Engineering and Manufacturing	Manufacturer		Deicer	MT35P75	Diesel	Fluid pump deice - 7.5 hp motor heating system is Jet A or diesel
Premier Engineering and Manufacturing	Manufacturer		Deicer	MT35P12	Diesel	Auxiliary power - Jet A or diesel compatible, fluid pump deice is electric 10 hp, heating system is jet A or diesel fired
Premier Engineering and Manufacturing	Manufacturer		Deicer	MT43P21-ABS	Diesel	Auxiliary power - Jet A and diesel compatible
Premier Engineering and Manufacturing	Manufacturer		Deicer	HC29050		Auxiliary power - gasoline engine 13 hp - heating power is Jet A or diesel fired
Premier Engineering and Manufacturing	Manufacturer		Deicer	MT85P27-ABS	Diesel	Auxiliary power - diesel that is Jet A and diesel compatible
Premier Engineering and Manufacturing	Manufacturer		Deicer	MT35P18	Diesel	Auxiliary power - diesel that is Jet A and diesel compatible
Global Ground Support	Manufacturer	Yes	Deicer	Regional 1200 TE-B	Diesel	Don't know if it's diesel for sure - it says "Auxiliary Engine Deutz 4 cylinder"
Global Ground Support	Manufacturer	Yes	Deicer	Regional 2200 TE	Diesel	Don't know if it's diesel for sure - it says "Auxiliary Engine Deutz 4 cylinder"
Global Ground Support	Manufacturer	Yes	Deicer	ER 2875 TE	Diesel	239 hp- Don't know if it's diesel for sure - it says "Auxiliary Engine Deutz 4 cylinder"
Global Ground Support	Manufacturer	Yes	Deicer	G600T	Gasoline	Gasoline engine with electric start and battery, 20 hp
Global Ground Support	Manufacturer	Yes	Deicer	Regional 700 TE-B	Diesel	Don't know if it's diesel for sure - it says "Auxiliary Engine Deutz 4 cylinder" - usually I see "Deutz Diesel")
Global Ground Support	Manufacturer	Yes	Deicer	The Orion	Diesel	
Ground Support Specialists LLC	Manufacturer		Disabled Passenger Lift Vehicle	GS 260		This is just a lift, it doesn't seem to have an engine/ battery charged
TLD	Manufacturer		Disabled Passenger Lift Vehicle	DT-5003		
TLD	Manufacturer		Disabled Passenger Lift Vehicle	DT-5003-D		
Hobart	Manufacturer		Distribution Panels	400 Hz	Electric	
Hercules	Distributor	Yes	Engine	G1600 CAT 1404		20-65 hp
Hercules	Distributor	Yes	Engine	G2300 GTA 3.7		27-84 hp
Hercules	Distributor	Yes	Engine	G3400 GTA 5.6		39-133 hp
Hercules	Distributor	Yes	Engine	GTA 4800		57-228 hp
Hercules	Distributor	Yes	Engine	D2300 DT 3.7		27-84 hp - used in lift trucks, generators, air compressors, etc.

List of Available Products (Sorted by Equipment Type)

Company	Distributor or Manufacturer	Participated in Research Project	Type of Equipment	Model	Fuel Type (Where Specified in Product Literature)	Notes
Hercules	Distributor	Yes	Engine	D3400 GTA 5.6		39-133 hp - used in lift trucks, generators, air compressors, chippers, etc.
Hercules	Distributor	Yes	Engine	D4800 D5000		57-228 hp - used in generators, air compressors, construction eq, farm tractors etc.
Hercules	Distributor	Yes	Engine	MWM 10 Series (4.10TCA, 6.10T, 6.10TCA)		
Hercules	Distributor	Yes	Engine	MWM 229 Series (D229-3, D229-4, D229-6, TD229-EC-6		
TLD	Manufacturer		Engine Start Unit	ACE-500		
TLD	Manufacturer		Engine Start Unit	ACE-600-400	Diesel	
TLD	Manufacturer		Engine Start Unit	ASU-600	Diesel	
TLD	Manufacturer		Engine Start Unit	ASU-600-150	Diesel	
TLD	Manufacturer		Engine Start Unit	ASU-600-100	Diesel	
FCX Systems	Manufacturer		External APU			
Omega Aviation	Distributor		Fork Lift	Hyster X-50	Propane Gasoline	
Omega Aviation	Distributor		Fork Lift	Toyta 7FGCU15	Propane Gasoline	
Omega Aviation	Distributor		Fork Lift	Taylor TYE200	Diesel	
FCX Systems	Manufacturer		Frequency Converter	Gate box/line drop compensator		400 Hz
Davin Inc	Distributor		Fuel Service Cart	Par-Kan Model FSC-550	Diesel	
Davin Inc	Distributor		Fuel Service Cart	Par-Kan Model FSC-300	Gasoline	
Omega Aviation	Distributor		Fuel Truck	Trailmaster 4700 International	Diesel	
Ground Support Specialists LLC	Manufacturer		Full Cab Custom Chassis	GS 400 I		97 hp
Davin Inc	Distributor		Generator	Hobart Model 120CU24P5	Diesel	
Davin Inc	Distributor		Generator	TLD Ace Model GPU-4090-T-Cup		
Hercules	Distributor	Yes	Generator Drive Power Units	7.4L V8, 5.7L V8, 4.3L V6, 3.0L 4 cyl	Natural Gas/LPG	
Carolina Ground Service Equip	Distributor		Ground Power AC	Davco GP400/60/28 AC/DC Combo	Diesel	2000 amp DC
Carolina Ground Service Equip	Distributor		Ground Power AC	Hobart 60G20S	Diesel	Detroit 3-71 diesel engine
Carolina Ground Service Equip	Distributor		Ground Power AC	Hobart 90CU24P5	Diesel	
Power Systems International	Manufacturer	Yes	Ground Power Systems			
Aero Specialties	Distributor	Yes	Ground Power Unit	Unitron UFC-20-40M KVA AC	Electric	
Aero Specialties	Distributor	Yes	Ground Power Unit	TLD GPU-4000 Series	Diesel	Revolving field generator/meets U.S. and Euro emissions standards
Aero Specialties	Distributor	Yes	Ground Power Unit	TLD GPU-4060-T-Cup 28.5 VDC	Diesel	Meets Tier 3 and Com 3 standards
Aero Specialties	Distributor	Yes	Ground Power Unit	GPU-4060 GPU 60KVA	Diesel	Diesel electronic engines with electronic engine governors
Aero Specialties	Distributor	Yes	Ground Power Unit	TLD GPU-4060-T-Cup	Diesel	Over sized engine
Aero Specialties	Distributor	Yes	Ground Power Unit	TLD GPU-4000 Series	Diesel	
Aero Specialties	Distributor	Yes	Ground Power Unit	Unitron GPC-120T 400 Hz	Electric	
Aero Specialties	Distributor	Yes	Ground Power Unit	Unitron GFC-150 T 400 Hz	Electric	
Aero Specialties	Distributor	Yes	Ground Power Unit	Unitron GFC-15M 400Hz	Electric	
Aero Specialties	Distributor	Yes	Ground Power Unit	Unitron GFC-180T 400 Hz	Electric	
Aero Specialties	Distributor	Yes	Ground Power Unit	Unitron GFC-25M 400 Hz	Electric	
Aero Specialties	Distributor	Yes	Ground Power Unit	Unitron GFC-37M 400 Hz	Electric	
Aero Specialties	Distributor	Yes	Ground Power Unit	Unitron GFC-60 M 400 Hz	Electric	
Aero Specialties	Distributor	Yes	Ground Power Unit	Unitron GFC-75M 400 Hz	Electric	
Aero Specialties	Distributor	Yes	Ground Power Unit	Unitron GFC-90M 400Hz	Electric	
Aviation Ground Equip	Distributor		Ground Power Unit	Jet-Ex 5D and 5DZ	Diesel	Engine – 99 hp
Aviation Ground Equip	Distributor		Ground Power Unit	400 - 600		50-60 Hz
Aviation Ground Equip	Distributor		Ground Power Unit	60 kVA Cummins QSB4.5	Diesel	Operates at 2400 RPM (110 hp)
Aviation Ground Equip	Distributor		Ground Power Unit	90 kVA Cummins QSB	Diesel	Tier 3. Operates at 2000 RPM (175 hp)

List of Available Products (Sorted by Equipment Type)

Company	Distributor or Manufacturer	Participated in Research Project	Type of Equipment	Model	Fuel Type (Where Specified in Product Literature)	Notes
Aviation Ground Equip	Distributor		Ground Power Unit	120 kVA Cummins QSB	Diesel	2000 RPM (220 hp)
Aviation Ground Equip	Distributor		Ground Power Unit	140 kVA Cummins QSB	Diesel	240 hp
Aviation Ground Equip	Distributor		Ground Power Unit	90 and 120k VA Deutz	Diesel	215 hp
Aviation Ground Equip	Distributor		Ground Power Unit	160 kVA Deutz	Diesel	276 hp
Aviation Ground Equip	Distributor		Ground Power Unit	180 kVA	Disel	276 hp
Carolina Ground Service Equip	Distributor		Ground Power Unit	AL2000G 28.5 VDC	Gasoline	
Carolina Ground Service Equip	Distributor		Ground Power Unit	Davco 7028 TVC Magnum	Diesel	
Carolina Ground Service Equip	Distributor		Ground Power Unit	Davco GP400/60/28 AC/DC Combo	Diesel	
FCX Systems	Manufacturer		Ground Power Unit	GPU060-C	Diesel	90 hp, Tier III engine
FCX Systems	Manufacturer		Ground Power Unit	GPU090-C-1	Diesel	155 hp, Tier III
FCX Systems	Manufacturer		Ground Power Unit	GPU120-C-2	Diesel	155 hp, Tier III
FCX Systems	Manufacturer		Ground Power Unit	GPU180-C-2	Diesel	270 hp, Tier III engine
FCX Systems	Manufacturer		Ground Power Unit	GPU028-600-C	Diesel	50 hp
Fricke	Distributor (used)		Ground Power Unit	Guinault 90 KVA	Diesel	
Fricke	Distributor (used)		Ground Power Unit	Guinault 100 KVA	Diesel	
Fricke	Distributor (used)		Ground Power Unit	Lechmotoren 28V DC	Diesel	
Hobart	Manufacturer		Ground Power Unit	Jet-Ex 5D and 5DZ	Diesel	99 hp engines
Hobart	Manufacturer		Ground Power Unit	400 or 600		May be electric
Hobart	Manufacturer		Ground Power Unit	90CU24 or 120CU24	Diesel	90 model is 165 hp and the 120 model is 200 hp
Hobart	Manufacturer		Ground Power Unit	90CU20	Diesel	175 hp
Hobart	Manufacturer		Ground Power Unit	90DZ20 or 120DZ20	Diesel	218 hp in both models
Hobart	Manufacturer		Ground Power Unit	60CU24	Diesel	110 hp
Hobart	Manufacturer		Ground Power Unit	140CU20	Diesel	240 hp
Hobart	Manufacturer		Ground Power Unit	140DZ20	Diesel	276 hp
Hobart	Manufacturer		Ground Power Unit	160DZ20	Diesel	276 hp
Hobart	Manufacturer		Ground Power Unit	180DZ20	Diesel	276 hp
Hobart	Manufacturer		Ground Power Unit	180CU20	Diesel	325 hp
Jetall	Distributor		Ground Power Unit	Davco AC20-TED	Diesel	Refurbished
Jetall	Distributor		Ground Power Unit	ACE 804-920	Diesel	
Jetall	Distributor		Ground Power Unit	Steward & Stevenson TMAC-255	Diesel	
Jetall	Distributor		Ground Power Unit	JTL 120D	Diesel	
Jetall	Distributor		Ground Power Unit	JTL 140D	Diesel	
Jetall	Distributor		Ground Power Unit	JTL 140DTR	Diesel	
Jetall	Distributor		Ground Power Unit	JTL 28D2	Diesel	
Omega Aviation	Distributor		Ground Power Unit	Davco 430-PSL-1316	Diesel	
Omega Aviation	Distributor		Ground Power Unit	TM-4750	Diesel	
Omega Aviation	Distributor		Ground Power Unit	Hobart 6002P	Diesel	
Start Pac	Manufacturer		Ground Power Unit	Self-Propelled Gasoline-Electric Hi-Brd	Gasoline	26 hp - Gas powered 28.5 VDC GPU: 12 gallon gas tank, fuel consumption: 1-1/2 gal – 2 gal per hour
Start Pac	Manufacturer		Ground Power Unit	Self-Propelled Diesel-Electric Hi-Brd	Diesel	Diesel engine- 21.5 horsepower. Meets EPA Tier 4 and EU State 111A exhaust emissions regulations. Fuel consumption: 1-1/2 gal – 2 gal per hour
Systems Integrators LLC	Manufacturer		Ground Power Unit	AL2000G 28.0	Gasoline	25 hp
Systems Integrators LLC	Manufacturer		Ground Power Unit	AL2000DZ 28.0	Diesel	47.5 hp
TLD	Manufacturer		Ground Power Unit	GPU-4060		
TLD	Manufacturer		Ground Power Unit	GPU-4000		
TLD	Manufacturer		Ground Power Unit	GPU-4090 Dut		
TLD	Manufacturer		Ground Power Unit	GPU-4090 Cut		
TLD	Manufacturer		Ground Power Unit	GPU-28		

List of Available Products (Sorted by Equipment Type)

Company	Distributor or Manufacturer	Participated in Research Project	Type of Equipment	Model	Fuel Type (Where Specified in Product Literature)	Notes
Tug Technologies	Manufacturer	Yes	Ground Power Unit	GP28M	Diesel	130bhp
Tug Technologies	Manufacturer	Yes	Ground Power Unit	GP400-60	Diesel/Jet A	130bhp
Tug Technologies	Manufacturer	Yes	Ground Power Unit	GP400-100	Diesel/Jet A	171bhp
Tug Technologies	Manufacturer	Yes	Ground Power Unit	GP400-120	Diesel/Jet A	203bhp
Tug Technologies	Manufacturer	Yes	Ground Power Unit	GP400-140	Diesel/Jet A	
Victory GSE	Distributor	Yes	Ground Power Unit	ACE-4120-24-DUP		
TCR	Distributor (rentals)		GSE	equipment listed for sale but no information on specs for listed equipment - see binder		
Aero Specialties	Distributor	Yes	Heater	MARK IV Coldbuster Flameless	Gasoline	Full equipment offered manual in binder. Meets government emission standards. Fuel tank capacity is 60 gallons.
Davin Inc	Distributor		Heater	Coldbuster Mark 1	Gasoline	
Jetall	Distributor		Heater	Air-A-Plane 5050D	Diesel	
TLD	Manufacturer		Heating Unit	ACU-2000	Gasoline	
Ground Support Specialists LLC	Manufacturer		Heavy Duty Wrecker	GS 405		61 hp
Tronair	Manufacturer		Hydraulic Power	50 & 51 series		3-5 hp depending on which model
Tronair	Manufacturer		Hydraulic Power	52, 53, 54 & 5J Series		15-30 hp depending on which model
Tronair	Manufacturer		Hydraulic Power	55, 56, & 57 series		40-75 hp depending on which model
Tronair	Manufacturer		Hydraulic Power	58, 59, 5A & 5L series		100-150 hp depending on which model
Hercules	Distributor	Yes	Industrial Power Units	7.4L V8, 5.7L V8, 4.3L V6, 3.0L 4 cyl	Natural Gas/ LPG	
Aero Specialties	Distributor	Yes	Lav Cart	LC100	Electric/ Gasoline	The LC100 comes with either a hand pump (LC100), electric pump (LC100E), or gas pump (LC100G)
Aero Specialties	Distributor	Yes	Lav Cart	LC270-RJ3		
Aero Specialties	Distributor	Yes	Lav Insert	LC270 Lav Insert	Electric/ Gasoline	Pump System: Honda gas or 12VDC electric system, the lav insert goes on the back of a pickup truck
Aero Specialties	Distributor	Yes	Lavatory Service Cart	LC60-RJ1		
Charlatte America	Manufacturer	Yes	Lavatory Service Cart	CLT-200E	Electric	40hp
Phoenix Metal Products Inc	Manufacturer		Lavatory Service Truck	TL175		Available Chassis Ford, Isuzu, and GMC
Phoenix Metal Products Inc	Manufacturer		Lavatory Service Truck	TL600		Available Chassis Ford, Isuzu, and GMC
Phoenix Metal Products Inc	Manufacturer		Lavatory Service Truck	TL600PL	Gasoline/ Diesel	Engine type optional
Phoenix Metal Products Inc	Manufacturer		Lavatory Service Truck	TL700		Available Chassis Ford, Isuzu, and GMC
TLD	Manufacturer		Lavatory Service Vehicle	LTM-900-V		
TLD	Manufacturer		Lavatory Service Vehicle	LTM-900		
TLD	Manufacturer		Lavatory Service Vehicle	LSP-900-V		
TLD	Manufacturer		Lavatory Service Vehicle	LSP-900		
Jetall	Distributor		Lavatory Truck	NEA TL600		
Jetall	Distributor		Lavatory Truck	NEA TL1000PL		
Mercury GSE	Distributor		Lavatory Truck	Wollard TLS-770A	Diesel	
Mercury GSE	Distributor		Lavatory Truck	Stinar SLS 350		
Mercury GSE	Distributor		Lavatory Truck	Stinar SLS 500 PL		
Aviation Ground Equip	Distributor		Light Tower	Rite-Lite Series		
TLD	Manufacturer		Loader	929		
TLD	Manufacturer		Loader	929-S		
TLD	Manufacturer		Loader	121		
TLD	Manufacturer		Loader	TXL-838 WID		

List of Available Products (Sorted by Equipment Type)

Company	Distributor or Manufacturer	Participated in Research Project	Type of Equipment	Model	Fuel Type (Where Specified in Product Literature)	Notes
TLD	Manufacturer		Loader	TXL-838 UNI		
TLD	Manufacturer		Loader	TXL-838 STD		
TLD	Manufacturer		Loader	TXL-838-COM		
TLD	Manufacturer		Loader	TXL-737-E		
TLD	Manufacturer		Loader	TXL-737		
TLD	Manufacturer		Loader	TXL-838-reGen	Electric	
TLD	Manufacturer		Loader	TXL-838 SUP		
Omega Aviation	Distributor		Main Deck Cargo Loader	MDL-40	Diesel	
Ground Support Specialists LLC	Manufacturer		Maintenance Lift	GS 600		97 hp
Ground Support Specialists LLC	Manufacturer		Maintenance Lift	GS 426SL		97 hp
Phoenix Metal Products Inc	Manufacturer		Maintenance Platform	CMHLM15	Gasoline/ Diesel	Three engines optional Deutz diesel F4M2011 3.1L, GMC gasoline VORTEC 3000 3.4 L, Perkins Diesel 1104C 4.4L
TLD	Manufacturer		Maintenance Platform	DT-6008		
TLD	Manufacturer		Maintenance Platform Vehicle	MAWP-48	Diesel	
TLD	Manufacturer		Maintenance Platform Vehicle	MAWP-52	Diesel	
TLD	Manufacturer		Maintenance Platform Vehicle	MLP-100-T	Diesel	
TLD	Manufacturer		Maintenance Platform Vehicle	MLP-95-T	Diesel	
Ground Support Specialists LLC	Manufacturer		Maintenance Service Vehicle	GS 650		97 hp
Ground Support Specialists LLC	Manufacturer		Material Handling Lift	GS 240C		This is just a lift, it doesn't seem to have an engine/ battery charged
Planet GSE	Distributor		Model and equipment type listed but no specs on particular pieces of equipment given			
Fortbrand Services Inc	Distributor		Mower	Bladestorm GST20		
Fortbrand Services Inc	Distributor		Multi-Task Airport Service Vehicle	VX 800		
TLD	Manufacturer		Pallet/Container Transporter	TF-7-GR		Electric and hydraulic circuits
TLD	Manufacturer		Pallet/Container Transporter	TF-10-FTC		Electric and hydraulic systems
TLD	Manufacturer		Pallet/Container Transporter	TF20-GR		
Davin Inc	Distributor		Passenger Stair	Stinar Model SPS-2513		
JBT AeroTech	Manufacturer		Passenger Stair	EUROstep		
JBT AeroTech	Manufacturer		Passenger Stair	NBS-2		
JBT AeroTech	Manufacturer		Passenger Stair	SmartStep-2		
Jetall	Distributor		Passenger Stair	Wollard MLPH307		The hydraulic pump is engine driven but I don't know the hp
Jetall	Distributor		Passenger Stair	Wollard 252SMT	Diesel	The hydraulic pump is engine driven but I don't know the hp
Jetall	Distributor		Passenger Stair	NEA-PAS200		The hydraulic pump is engine driven but I don't know the hp
Omega Aviation	Distributor		Passenger Stair	Nodco 3005-7	Gasoline	
Omega Aviation	Distributor		Passenger Stair	Stinar SPS2513	Gasoline	
Omega Aviation	Distributor		Passenger Stair	Wollard MLPH309	Gasoline	
Phoenix Metal Products Inc	Manufacturer		Passenger Stair	CMPPS96/150	Gasoline/ Diesel	Two engines optional - Deutz diesel F4M2011 3.1L or GMC gasoline VORTEC 3000 3.4 L
TLD	Manufacturer		Passenger Stair	ABS-580		
TLD	Manufacturer		Passenger Stair	ABL-580	Electric	
TLD	Manufacturer		Passenger Stair	BBS-580		
TLD	Manufacturer		Passenger Stair	ABS-580E		
TLD	Manufacturer		Passenger Stair	ABS-2045	Diesel	
Volk	Manufacturer		Platform Truck	EFW 5	Electric	DC/DC Converter 80/12 volt electrical system drive is 80 volt three-phase asynchronous motor

List of Available Products (Sorted by Equipment Type)

Company	Distributor or Manufacturer	Participated in Research Project	Type of Equipment	Model	Fuel Type (Where Specified in Product Literature)	Notes
Volk	Manufacturer		Platform Truck	EFW 4	Electric	DC/DC Converter 80/12 volt electrical system drive is 80 volt three-phase asynchronous motor
Volk	Manufacturer		Platform Truck	EFW 3	Electric	DC/DC Converter 80/12 volt electrical system drive is 80 volt three-phase asynchronous motor
Volk	Manufacturer		Platform Truck	EFW 2	Electric	DC/DC Converter 80/12 volt electrical system drive is 80 volt three-phase asynchronous motor
Volk	Manufacturer		Platform Truck	EFW 1.5	Electric	DC/DC Converter 80/12 volt electrical system drive is 80 volt three-phase asynchronous motor
Volk	Manufacturer		Platform Truck	EFW 1	Electric	24 volt electric system and 24 volt three-phase asynchronous motor drive
Volk	Manufacturer		Platform Truck	EFQ 0.3	Electric	Electric system is battery plug-in and drive is 24 volt three-phase asynchronous motor
Volk	Manufacturer		Platform Truck	DFW 5	Diesel	
Volk	Manufacturer		Platform Truck	DFW 4	Diesel	
Volk	Manufacturer		Platform Truck	DFW 3	Diesel	
Volk	Manufacturer		Platform Truck	DFW 2	Diesel	
Volk	Manufacturer		Platform Truck	TFW 5	LPG	
Volk	Manufacturer		Platform Truck	TFW 4	LPG	
Volk	Manufacturer		Platform Truck	TFW 3	LPG	
Volk	Manufacturer		Platform Truck	TFW 2	LPG	
Fortbrand Services Inc	Distributor		Plow	PS4200		
Fortbrand Services Inc	Distributor		Plow Sweeper Blower	Vammas PSB 5500		475 hp
Aero Specialties	Distributor	Yes	Potable Water Cart	WC100E	Electric	
Aero Specialties	Distributor	Yes	Potable Water Cart	WC30E	Electric	
Aero Specialties	Distributor	Yes	Potable Water Cart	WC80-RJ1	Electric	
Phoenix Metal Products Inc	Manufacturer		Potable Water Service Truck	WT450		Available chassis Ford, Isuzu, and GMC
Phoenix Metal Products Inc	Manufacturer		Potable Water Service Truck	WT600PL		Available chassis Ford, Isuzu, and GMC
TLD	Manufacturer		Potable Water Service Vehicle	WSP-900		
TLD	Manufacturer		Potable Water Service Vehicle	WTM-900		
Ground Support Specialists LLC	Manufacturer		Potable Water/Lavatory Services	GS 400		51 hp
Ground Support Specialists LLC	Manufacturer		Potable Water/Lavatory Services	GS 450		51 hp
Ground Support Specialists LLC	Manufacturer		Potable Water/Lavatory Services	GS 451		51 hp
Aero Specialties	Distributor	Yes	Power Cart	Aero HMA Series Hydraulic		
Unitron	Manufacturer	Yes	Preconditioned Air	DS-2210	Diesel/Jet A/ Jet A1/JP-5/ JP-8	
Unitron	Manufacturer	Yes	Preconditioned Air	DS-3215	Diesel/Jet A/ Jet A1/JP-5/ JP-8	
Unitron	Manufacturer	Yes	Preconditioned Air	DS-4224	Diesel/Jet A/ Jet A1/JP-5/ JP-8	
Aviation Ground Equip	Distributor		Preconditioned Air	DAC200	Diesel/Jet Fuel	Noted that engines are diesel and jet fuel compatible
Aviation Ground Equip	Distributor		Preconditioned Air	DAC300	Diesel/Jet Fuel	Noted that engines are diesel and jet fuel compatible
Aviation Ground Equip	Distributor		Preconditioned Air	5080DE	Diesel/Jet Fuel	Noted that engines are diesel and jet fuel compatible
Aviation Ground Equip	Distributor		Preconditioned Air	DAC900	Diesel/Jet Fuel	Noted that engines are diesel and jet fuel compatible
Aviation Ground Equip	Distributor		Preconditioned Air	POU200	Electric	
Aviation Ground Equip	Distributor		Preconditioned Air	POU300	Electric	

List of Available Products (Sorted by Equipment Type)

Company	Distributor or Manufacturer	Participated in Research Project	Type of Equipment	Model	Fuel Type (Where Specified in Product Literature)	Notes
Aviation Ground Equip	Distributor		Preconditioned Air	DXU60	Electric	
Aviation Ground Equip	Distributor		Preconditioned Air	DXU90	Electric	60 hp blower motor
Phoenix Metal Products Inc	Manufacturer		Provisioning Van	PV120	Diesel	
Global Ground Support	Manufacturer	Yes	Recovery Vehicle	Glycol	Diesel	
Bosserman	Manufacturer		Refueler	ERF750MM-50A	Electric	55 hp
Bosserman	Manufacturer		Refueler	RF750MM-50A	Diesel	
Bosserman	Manufacturer		Refueler	RF1000SC-50A	Diesel	
Bosserman	Manufacturer		Refueler	RF1500	Diesel	
Bosserman	Manufacturer		Refueler	R2500J-200RM	Diesel	
Bosserman	Manufacturer		Refueler	RF3000SC-300	Diesel	
Bosserman	Manufacturer		Refueler	RF5000SC-3000	Diesel	
Bosserman	Manufacturer		Refueler	RF6000SC-600	Diesel	
Bosserman	Manufacturer		Refueler	RF7000SC-300	Diesel	
Bosserman	Manufacturer		Refueler	RF8000SC-300	Diesel	
Bosserman	Manufacturer		Refueler	RF10,000SC-800	Diesel	
Fortbrand Services Inc	Distributor		Refueler	"AV-Gas refueler"	AV-Gas	
Fortbrand Services Inc	Distributor		Snow Blower	Vammas B 400		563 hp
Fortbrand Services Inc	Distributor		Snow Sweeper	Fresia F2000	Diesel	Two Iveco engines - 425 hp
Mercury GSE	Distributor		Stair Truck	Nordco 3003		
Fortbrand Services Inc	Distributor		Sweeper	Vammas SB Series 3600 or 4500		349 hp or 420 hp, respectively
Fortbrand Services Inc	Distributor		Sweeper	Vammas RSB 3600		349 hp
Charlatte America	Manufacturer	Yes	Tow Hitch	TE.206	Electric	8 hp
Charlatte America	Manufacturer	Yes	Tow Hitch	TE.208	Electric	8 hp
JBT AeroTech	Manufacturer		Towbarless Tractor	Expediter 400		
JBT AeroTech	Manufacturer		Towbarless Tractor	Expediter 160		
JBT AeroTech	Manufacturer		Towbarless Tractor	Expediter 300		
Hobart	Manufacturer		Transformer	TR-1528	Electric	
TLD	Manufacturer		Truck Loader	TFE7-GR		Electric and hydraulic circuits
Charlatte America	Manufacturer	Yes	Universal Chassis	DC3	Diesel	64.5 hp - Can be used as a lavatory truck, passenger stairs, hi-lift catering van, hi-lift cleaning van or hi-lift maintenance platform
Tug Technologies	Manufacturer	Yes	Utility Vehicle	Model MH	Diesel/Jet A	
Ground Support Specialists LLC	Manufacturer		Utility Vehicle	GS 450		97 HR
TLD	Manufacturer		Vehicle with lift	CHTP GM-5.9		
TLD	Manufacturer		Vehicle with lift	CHTP-PM5.9		
TLD	Manufacturer		Vehicle with lift	CH BM 5.9		
TLD	Manufacturer		Vehicle with lift	CH Jumbo 5.9		
Aero Specialties	Distributor	Yes	Water Cart	WC270-RJ3	Electric/ Gasoline	Fill pump: Electric-start Honda gas engine or 12V DC electric system
Phoenix Metal Products Inc	Manufacturer		Water Service Truck	WT700		Available chassis: Ford, Isuzu, and Chevrolet
Jetall	Distributor		Water Service Truck	NEA450		
Jetall	Distributor		Water Service Truck	NEA700		

APPENDIX B

Air Pollutant Emission Factors for GSE

Emission Factors

For an individual piece of GSE (with the exception of electric GSE), the amount of engine exhaust emissions of the criteria air pollutants (and their precursors), hazardous air pollutants (HAPs), and greenhouse gases (GHGs) is largely dependent on the size of the engine [typically expressed in brake horsepower (BHP)], the fuel type (e.g., diesel, gas), the engine on/run time, and load factor. [Load factors are values that represent the ratio of the average energy demand of the equipment (the load) to the maximum (peak load) of the equipment.]

The following materials present standard methodologies for computing these emissions from the operation/use of GSE.

Criteria Air Pollutant Emissions

The FAA's *Air Quality Handbook* provides the following equations for conventional/alternative-fuel GSE and for electric GSE.

Conventional/Alternative-Fuel GSE

$$E_{it} = (BHP_t \times LF_t \times U_t \times EI_{it}) \times CF$$

Where:

E_{it} = Emissions of pollutant i, in pounds, produced by GSE type t
BHP_t = Average rated BHP of the engine for equipment type t
LF_t = Load factor for equipment type t
U_t = Hours of equipment use
EI_{it} = Emission index (factor) for pollutant i in grams per BHP-hr
$_i$ = Pollutant of interest (e.g., carbon monoxide, volatile organic compounds)
$_t$ = Equipment type (e.g., baggage tug)
CF = Factor to convert grams to pounds (0.0022046)

Electric GSE

Electric GSE do not produce emissions at airports. Rather, the emissions resulting from the use of electricity are those from the local or regional power plant. The emissions from the power plant that would be attributable to the use of electric GSE at an airport can be calculated as follows:

$$E_{it} = BHP_t \times LF_t \times U_t (EI_{it} \times CFBHP \times CF)$$

Organic Gases/HAPs

In 2009, the FAA published guidance that provides a method for estimating emissions of organic gases (which include HAPs) from airport sources. The guidance document, entitled *Guidance for Quantifying Speciated Organic Gas Emissions from Airport Sources,* provides a detailed discussion of the various groups of organic gases [i.e., total organic gases (TOG), non-methane organic gases (NMOG), total hydrocarbons (THC), and volatile organic compounds (VOC)] that must be considered when estimating this type of emission.

The FAA's method of preparing an estimate of organic gases/HAPs essentially involves the following steps:

- Prepare an estimate of GSE-related TOG, NMOG, THC, or VOC
- If necessary, use conversion factors to convert estimates of NMOG, THC, or VOC to TOG
- Apply speciation profiles, in the form of mass fractions, to the TOG to estimate quantities of individual organic gases.

The individual organic gases/HAPs that are identified by the FAA as being of interest and emitted by GSE that are powered by gas, natural gas, liquid petroleum gas, and diesel are listed in Table B-1. These gases listed are either specially identified by the U.S. EPA to be a HAP or listed in U.S. EPA's Integrated Risk Information System (IRIS).

The FAA's formula to speciate GSE-related TOG emissions to obtain estimates of the individual organic gases above is expressed as:

$$L \times M \times B \times D \times F \times H \times 1/453.6 \times 1/60 = I$$

Where:

L = Average rated BHP
M = Load factor (percentage)
B = Time in operation (min)
D = OG emissions index (grams/BHP-hr)
F = TOG conversion factor (unitless)

Table B-1. Organic gases/HAPs emitted by GSE.

		Identified in:		Fuel Type	
Chemical Abstract Service No.	Species Name	Clean Air Act as HAP?	U.S. EPA's IRIS?	Gas, Natural Gas, and Liquid Petroleum Gas	Diesel
540841	2,2,4-trimethylpentane	Yes	Yes	•	
75070	acetaldehyde	Yes	Yes		•
100527	benzaldehyde		Yes		•
71432	benzene	Yes	Yes	•	
100414	ethylbenzene	Yes	Yes	•	
50000	formaldehyde	Yes	Yes		•
108383	m-xylene	Yes	Yes	•	
142825	n-heptane		Yes	•	
110543	n-hexane	Yes	Yes	•	
95476	o-xylene	Yes	Yes	•	
123386	propionaldehyde	Yes			•
108883	toluene	Yes	Yes	•	

H = Speciation profile for individual OG of interest (mass fraction)
I = Mass of OG of interest (pounds)
1/453.6 = grams to pounds conversion factor
1/60 = minutes to hour conversion factor

Greenhouse Gases

The U.S. EPA's method of estimating GHGs from GSE is similar to the approach recommended by the Intergovernmental Panel on Climate Change (IPCC) which is based on the total amount of fossil fuel consumed (combusted) for any given process/equipment use.

Because each individual GHG has a different Global Warming Potential (GWP), emission estimates are typically expressed as carbon dioxide (CO_2) equivalents (CO_2e). Use of CO_2e values allows direct comparisons between sources and time periods.

To determine Emissions and Dispersion Modeling System (EDMS) emissions factors for CO_2, methane (CH_4) and nitrous oxide (N_2O), the fuel consumption of a specific piece of GSE must first be computed according to the following formula:

$$F_t = FF_t \times L_t \times M_t \times B_t \times 1/453.6 \times 1/D_t$$

Where:

F_t = Gallons (or ft^3 for CNG) of fuel consumed by equipment t
FF_t = EDMS fuel flow rate for equipment t (in grams per horsepower-hour [g/hp-hr])
L_t = Rate BHP for equipment t
M_t = Load factor (percentage) for equipment t
B_t = Hours of operation for equipment t (= 1)
1/453.6 = grams to pounds conversion factor
D_t = fuel density for equipment t (in pounds of fuel per gallon or cubic foot consumed)[3]

Once the fuel consumption has been calculated, full-throttle GHG emissions factors for the equipment can be obtained as a function of fuel-specific emissions factors supplied by the U.S. Energy Information Administration[4] applied to the derived fuel consumption, as well as the equipment's specific engine parameters, as indicated in the formula below:

$$EF_{it} = F_t \times EF_i \times 453.6 \times 1/L_t \times 1/M_t \times 1/B_t$$

Where:

EF_{it} = Emissions of pollutant i (in pounds) produced by GSE type t
F_t = Gallons (or ft^3 for CNG) of fuel consumed by equipment t
EF_i = Emissions factor for GHG_i [in pounds of pollutant per gallon (or ft^3) of fuel]
453.6 = pounds to grams conversion factor
L_t = Rate BHP for equipment t
M_t = Load factor (percentage) for equipment t
B_t = Hours of operation for equipment t (= 1)

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[3]Fuel densities adapted from the U.S. EPA Compilation of Air Pollutant Emissions Factors (AP-42) and correspond to 7.1 lb/gal for diesel, 6.2 lb/gal for gasoline, 4.24 lb/gal for LPG, and 0.042 lb/ft^3 for CNG.

[4]U.S. Energy Information Administration—Independent Statistics and Analysis Voluntary Reporting of Greenhouse Gases Program—Fuel Emission Coefficients, accessed at http://www.eia.doe.gov/oiaf/1605/coefficients.html 1/31/2011.

As mentioned, individual GHG emissions factors can be normalized to CO_2e by applying 100-year time horizon GWPs as recommended by the IPCC's Fourth Assessment Report. These GWPs correspond to 1 for CO_2, 25 for CH_4 and 298 for N_2O.

Emissions and Dispersion Modeling System

A list of GSE with corresponding data that were extracted from the FAA's EDMS for the model's current reference equipment (i.e., the equipment for which the emissions data in EDMS are representative) is provided in Table B-2. For the purpose of comparing the emission factors of various fuel types for the same type of GSE, emission factors, extracted from the EDMS for the year 2011 are also provided in Table B-2. This list further provides, by equipment/fuel type, the FAA's speciation profiles for the calculation of organic gases/HAPs, and calculated emission factors for GHGs (CO_2, CH_4, and N_2O—the most prevalent GHGs).

Table B-2. Powered GSE uses and parameter values from EDMS.

Type of GSE	Equipment Use	ID	Ref Model	Fuel	HP	LF	UL	Use[b]	CO	VOC[d]	NO_x	SO_x	PM_{10}	$PM_{2.5}$	CO_2	N_2O	CH_4	On/Off Road	Used by Aircraft Type[c]: Large Passenger – Wide Body	Large Passenger – Narrow Body	Commuter – Turboprop	Commuter – Jet	General Aviation – Jet	General Aviation – Prop	Large Cargo – Wide Body	Large Cargo – Narrow Body	Used At: Climate – Warm	Climate – Cold	Airport w/Gate Power & PCA	Airport w/ Underground Fueling	Representative Manufacturers	Notes
Air conditioner (Mobile preconditioned air unit)	Provides conditioned air to ventilate and heat/cool parked aircraft.	1	ACE 802	D	300	0.8	13	808	0.94	0.28	3.66	0.01	0.24	0.23	524.82	0.005	0.013	Off									Yes	Yes	No	Yes	Air-A-Plane, ACE, Engineered Air System, Trilectron, Stewart & Stevenson	Not typically used at gates equipped with pre-conditioned air (PCA).
		2	ACE 804	D	210	0.8	13	808	0.94	0.28	3.66	0.01	0.24	0.23	524.82	0.005	0.013	Off														
		3	None	E	0	0.8	13	808										NA	•	•												
Air start	Provides large volumes of compressed air to an aircraft's main engines for starting.	4	ACE 180	D	425	0.9	10	333	1.24	0.25	4.65	0.01	0.18	0.18	524.82	0.005	0.013	Off	•	•					•	•	Yes	Yes	No	Yes	Davco, Trilectron, Garret, Stewart & Stevenson	Not typically used at gates equipped with 400 Hz.
		5	ACE 300/400	D	850	0.9	10	333	1.24	0.25	4.65	0.01	0.18	0.18	524.82	0.005	0.013	Off														
Aircraft (pushback) tractor	Used to tow and push aircraft in the terminal, ramp, and hanger areas.	6	Douglas TBL-400	D	617	0.8	14	641	1.44	0.32	4.22	0.01	0.27	0.27	524.82	0.005	0.013	Off											Yes	Yes	Equitech, Grove, Hough, Stewart & Stevenson, Tug, Inc., United, Victory GSE,	
		7	None	E	0	0.8	14	300										NA														
		8	S&S TUG GT-35, Douglas TBL-180	D	88	0.8	14	800	1.44	0.32	4.22	0.01	0.27	0.27	583.45	0.005	0.014	Off		•						•						
		9	S&S TUG GT-35, MC	C	110	0.8	14	800										Off														
		9	S&S TUG GT-35, MC	G	124	0.8	14	800	103.79	3.04	5.46	0.16	0.07	0.06				Off														

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Table B-2. (Continued).

Type of GSE	Equipment Use	ID	Ref Model	Fuel	HP	LF	UL	Use[b]	CO	VOC[d]	NO_x	SO_x	PM_{10}	$PM_{2.5}$	CO_2	N_2O	CH_4	On/Off Road	Used by Aircraft Type[c]: Large Passenger: Wide Body	Large Passenger: Narrow Body	Commuter: Turboprop	Commuter: Jet	General Aviation: Jet	General Aviation: Prop	Large Cargo: Wide Body	Large Cargo: Narrow Body	Used At: Climate: Warm	Used At: Climate: Cold	Airport w/Gate Power & PCA	Airport w/ Underground Fueling	Representative Manufacturers	Notes
Aircraft (push-back) tractor (continued)		9	S&S TUG GT-35, MC	L	124	0.8	14	800										Off														
		10	S&S TUG GT-50H	D	190	0.8	14	628	1.44	0.32	4.22	0.01	0.27	0.27	524.82	0.005	0.013	Off			•											
		11	S&S TUG MC	D	86	0.8	14	800	1.44	0.32	4.22	0.01	0.27	0.27	583.45	0.005	0.014	Off				•	•									
		12	S&S TUG T-750	D	475	0.8	14	641	1.44	0.32	4.22	0.01	0.27	0.27	524.82	0.005	0.013	Off	•						•							
Baggage tractors	Used to tow baggage carts or freight between an aircraft and the terminal or sorting facility.	13	S&S TUG MA 50	C	83	0.6	13	1,500	29.84	0.00	5.42	0.01	0.06	0.06	528.77	0.001	0.001	Off													Clark, Equitech, Hartan, Northwestern, NMC-Wollard, Tug, Inc., United	Time in use less at airports with baggage conveyor systems (e.g., TPA).
		13	S&S TUG MA 50	D	71	0.6	13	1,500	3.87	0.35	4.02	0.01	0.49	0.48	583.45	0.005	0.014	Off														
		13	S&S TUG MA 50	E	0	0.6	13	1,500										NA									Yes	Yes	Yes	Yes		
		13	S&S TUG MA 50	G	107	0.6	13	1,500	90.66	2.62	4.69	0.16	0.07	0.06	692.75	0.007	0.019	Off	•	•	•											
		13	S&S TUG MA 50	L	107	0.6	13	1,500	29.84	1.20	5.42	0.01	0.06	0.06	550.26	0.000	0.000	Off														
Belt loaders	Mobile conveyor belts used to move baggage between the ground and an aircraft hold.	14	S&S TUG 660	C	83	0.5	11	1,300	19.92	0.00	4.54	0.01	0.06	0.06	528.77	0.001	0.001	Off														Used mainly for narrow and medium body aircraft.
		14	S&S TUG 660	D	71	0.5	11	1,300	2.54	0.36	4.27	0.01	0.38	0.37	583.45	0.005	0.014	Off														
		14	S&S TUG 660	E	0	0.5	11	800										NA									Yes	Yes	Yes	Yes		
		14	S&S TUG 660	G	107	0.5	11	1,300	45.92	1.38	3.13	0.15	0.07	0.06	692.75	0.007	0.019	Off	•	•	•				•	•						
		14	S&S TUG 660	L	107	0.5	11	1,300	19.92	0.74	4.54	0.01	0.06	0.06	550.26	0.000	0.000	Off														
Bobtail	All purpose vehicle capable of handling towed GSE, narrow- and wide-body air cargo, and plowing snow.	15	Eagle Bobtail/ F350	C	110	0.6	10	1,867										Off													Global Ground Support	
		15	Eagle Bobtail/ F350	D	235	0.6	10	1,867	1.57	0.33	4.14	0.01	0.34	0.33	524.82	0.005	0.013	Off														
		15	Eagle Bobtail/ F350	G	124	0.6	10	1,867	72.59	2.04	3.68	0.15	0.07	0.06	692.75	0.007	0.019	Off									Yes	Yes	Yes	Yes		
		15	Eagle Bobtail/ F350	L	124	0.6	10	1,867										Off														

Buses	Shuttles passenger and airport personnel between facility locations.																	On									Yes	Yes	Yes	Yes		Used mostly at hub airports without people mover systems.
Cabin service truck	Used for cleaning aircraft and replenishing supplies.	16	Hi-Way/TUG 660 chassis	C	83	0.5	10	1,600	30.10	0.00	5.51	0.01	0.06	0.06	528.77	0.001	0.001	On									Yes	Yes	Yes	Yes	Global Ground Support	Commonly classified as "on-road" vehicles.
		16	Hi-Way/TUG 660 chassis	D	71	0.5	10	1,600	0.35	0.19	0.74	0.01	0.03	0.03	583.45	0.005	0.014	On														
		16	Hi-Way/TUG 660 chassis	E	0	0.5	10	1,600										NA														
		16	Hi-Way/TUG 660 chassis	G	107	0.5	10	1,600	6.91	0.70	1.98	0.14	0.06	0.06	692.75	0.007	0.019	On														
		16	Hi-Way/TUG 660 chassis	L	107	0.5	10	1,600	30.10	1.22	5.51	0.01	0.06	0.06	550.26	0.000	0.000	On														
		17	Hi-Way F650	C	360	0.5	10	1,600	30.10	0.00	5.51	0.01	0.06	0.06	528.77	0.001	0.001	On														
		17	Hi-Way F650	D	210	0.5	10	1,600	0.35	0.19	0.74	0.01	0.03	0.03	524.82	0.005	0.013	On	•	•												
		17	Hi-Way F650	G	260	0.5	10	1,600	6.91	0.70	1.98	0.14	0.06	0.06	692.75	0.007	0.019	On														
		17	Hi-Way F650	L	260	0.5	10	1,600	30.10	1.22	5.51	0.01	0.06	0.06	550.26	0.000	0.000	On														
Cargo (Container) Loader	Used to load containers onto large cargo and other aircraft.	18	FMC Commander 15	C	83	0.5	11	1,100	33.00	0.01	6.55	0.01	0.06	0.06	528.77	0.001	0.001	Off									Yes	Yes	Yes	Yes		
		18	FMC Commander 15	D	80	0.5	11	1,100	2.57	0.72	4.69	0.01	0.57	0.55	583.45	0.005	0.014	Off	•						•							
		18	FMC Commander 15	E	0	0.5	11	700										NA														
		18	FMC Commander 15	G	107	0.5	11	1,100	57.89	1.59	2.92	0.15	0.07	0.06	692.75	0.007	0.019	Off														
		18	FMC Commander 15	L	107	0.5	11	1,100	33.00	1.41	6.55	0.01	0.06	0.06	550.26	0.000	0.000	Off														
		19	FMC Commander 30	D	133	0.5	11	1,100	2.57	0.72	4.69	0.01	0.57	0.55	524.82	0.005	0.013	Off														
Cargo Tractor		20	S&S TUG MT	C	83	0.5	13	1349	29.74	0.00	5.39	0.01	0.06	0.06	528.77	0.001	0.001	Off									Yes	Yes	Yes	Yes		
		20	S&S TUG MT	D	88	0.5	13	1349	4.21	0.54	4.89	0.01	0.63	0.61	583.45	0.005	0.014	Off							•							
		20	S&S TUG MT	G	107	0.5	13	1349	35.87	0.93	1.82	0.15	0.07	0.06	692.75	0.007	0.019	Off														
		20	S&S TUG MT	L	107	0.5	13	1349	29.74	1.19	5.39	0.01	0.06	0.06	550.26	0.000	0.000	Off														

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Table B-2. (Continued).

Type of GSE	Equipment Use	ID	Ref Model	Fuel	HP	LF	UL	Use[b]	CO	VOC[d]	NO_x	SO_x	PM_{10}	$PM_{2.5}$	CO_2	N_2O	CH_4	On/Off Road	Used by Aircraft Type[c]: Large Passenger: Wide Body	Large Passenger: Narrow Body	Commuter: Turboprop	Commuter: Jet	General Aviation: Jet	General Aviation: Prop	Large Cargo: Wide Body	Large Cargo: Narrow Body	Used At: Climate: Warm	Climate: Cold	Airport w/Gate Power & PCA	Airport w/ Underground Fueling	Representative Manufacturers	Notes
Cars/Pickup trucks	Move airport personnel around facility for administrative and maintenance purposes.																	On									Yes	Yes	Yes	Yes		Commonly classified as "on-road" vehicles.
Carts	Used as personnel carriers.	21	Taylor Dunn	C	25	0.5	14	100										Off									Yes	Yes	Yes	Yes		Small gasoline or electric-powered non-road vehicles.
		21	Taylor Dunn	D	25	0.5	14	100										Off														
		21	Taylor Dunn	G	25	0.5	14	100	103.74	3.04	5.46	0.16	0.07	0.06	1059.2	0.011	0.030	Off														
		21	Taylor Dunn	L	25	0.5	14	100										Off														
Catering truck	Used to unload unused food/drinks and restock food/drinks for passenger and crew meals.	22	Hi-Way/TUG 660 chassis	C	83	0.5	10	1,600	30.10	0.00	5.51	0.01	0.06	0.06	528.77	0.001	0.001	On									Yes	Yes	Yes	Yes	Hi-Way, Global Ground Support	
		22	Hi-Way/TUG 660 chassis	D	71	0.5	10	1,600	0.35	0.19	0.74	0.01	0.03	0.03	583.45	0.005	0.014	On			•											
		22	Hi-Way/TUG 660 chassis	E	0	0.5	10	1,600										NA														
		22	Hi-Way/TUG 660 chassis	G	107	0.5	10	1,600	6.91	0.70	1.98	0.14	0.06	0.06	692.75	0.007	0.019	On														
		22	Hi-Way/TUG 660 chassis	L	107	0.5	10	1,600	30.10	1.22	5.51	0.01	0.06	0.06	550.26	0.000	0.000	On														
		23	Hi-Way F650	C	360	0.5	10	1,600	30.10	0.00	5.51	0.01	0.06	0.06	528.77	0.001	0.001	On														
		23	Hi-Way F650	D	210	0.5	10	1,600	0.35	0.19	0.74	0.01	0.03	0.03	524.82	0.005	0.013	On	•	•												
		23	Hi-Way F650	G	260	0.5	10	1,600	6.91	0.70	1.98	0.14	0.06	0.06	692.75	0.007	0.019	On														
		23	Hi-Way F650	L	260	0.5	10	1,600	30.10	1.22	5.51	0.01	0.06	0.06	550.26	0.000	0.000	On														

Deicing/anti-icing vehicles	Most known for removal of ice from aircraft prior to departure but may be equipped with aircraft washing equipment.	24	FMC LMD, Dual engine	C	270	1	14	500										On									No	Yes	Yes	Yes	Global Ground Support	Vehicles equipped with both deicing and washing equipment, could be used in both warm and cold climates
		24	FMC LMD, Dual engine	D	263	1	14	500										On														
		24	FMC LMD, Dual engine	G	270	1	14	500	71.79	2.32	5.31	0.16	0.07	0.06	692.75	0.007	0.019	On														
		24	FMC LMD, Dual engine	L	270	1	14	500										On														
		25	FMC Tempest II, Single engine	C	83	1	14	500										On														
		25	FMC Tempest II, Single engine	D	165	1	14	500										On														
		25	FMC Tempest II, Single engine	G	107	1	14	500	71.79	2.32	5.31	0.16	0.07	0.06	692.75	0.007	0.019	On														
		25	FMC Tempest II, Single engine	L	107	1	14	500										On														
Forklifts	Used to move heavy cargo (typically for wide-body aircraft).	26	Toyota 5,000 lb	C	54	0.3	13	976	27.20	0.00	4.55	0.01	0.06	0.06	528.77	0.001	0.001	Off									Yes	Yes	Yes	Yes		
		26	Toyota 5,000 lb	D	55	0.3	13	976	3.35	0.90	5.67	0.01	0.65	0.63	583.45	0.005	0.014	Off														
		26	Toyota 5,000 lb	G	54	0.3	13	976	103.74	3.04	5.46	0.16	0.07	0.06	692.75	0.007	0.019	Off														
		26	Toyota 5,000 lb	L	54	0.3	13	976	27.20	1.03	4.55	0.01	0.06	0.06	550.26	0.000	0.000	Off														
Fuel trucks	Used to fuel aircraft in the absence of a hydrant system.	27	Dukes / DART 8000 to 10000 gal	D	300				0.55	0.24	1.84	0.01	0.04	0.04	524.82	0.005	0.013	On									Yes	Yes	NA	No		
		28	F350	C	360				33.00	0.01	6.55	0.01	0.06	0.06	528.77	0.001	0.001	On														
		28	F350	D	235				0.55	0.24	1.84	0.01	0.04	0.04	524.82	0.005	0.013	On														
		28	F350	G	260				7.34	0.87	2.45	0.14	0.06	0.06	692.75	0.007	0.019	On														
		28	F350	L	260				33.00	1.41	6.55	0.01	0.06	0.06	550.26	0.000	0.000	On														
		29	F750, Dukes, DART 3000 to 6000	C	420				33.00	0.01	6.55	0.01	0.06	0.06	528.77	0.001	0.001	On														
		29	F750, Dukes, DART 3000 to 6000	D	175				0.55	0.24	1.84	0.01	0.04	0.04	524.82	0.005	0.013	On			•	•	•	•								
		29	F750, Dukes, DART 3000 to 6000	G	420				7.34	0.87	2.45	0.14	0.06	0.06	692.75	0.007	0.019	On														
		29	F750, Dukes, DART 3000 to 6000	L	420				33.00	1.41	6.55	0.01	0.06	0.06	550.260	0.000	0.000	On														

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Table B-2. (Continued).

Type of GSE	Equipment Use	ID	Ref Model	Fuel	HP	LF	UL	Use[b]	CO	VOC[d]	NO_x	SO_x	PM_{10}	$PM_{2.5}$	CO_2	N_2O	CH_4	On/Off Road	Used by Aircraft Type[c]: Large Passenger – Wide Body	Large Passenger – Narrow Body	Commuter – Turboprop	Commuter – Jet	General Aviation – Jet	General Aviation – Prop	Large Cargo – Wide Body	Large Cargo – Narrow Body	Used At: Climate – Warm	Climate – Cold	Airport w/Gate Power & PCA	Airport w/ Underground Fueling	Representative Manufacturers	Notes
Generator	A machine that converts mechanical energy into electrical energy.	30	None	C	107	0	10	0										Off									Yes	Yes	Yes	Yes		
		30		D	158	0.8	10	1,630	1.30	0.39	5.06	0.01	0.29	0.28				Off														
		30		G	107	0.8	10	900	71.89	2.32	5.32	0.16	0.07	0.06				Off														
		30		L	107	0	10	0										Off														
Ground power units	Mobile generator units that supply aircraft with electricity while parked.	31	TLD	C	83	0.8	10	1,600										Off									Yes	Yes	No	Yes	Arvico, Hobart, Stewart & Stevenson, TLD, Tronair, Global Ground Support	Used less at airports with gate electricity. Used for commuter aircraft.
		31	TLD	E	0	0.8	10	0										NA														
		31	TLD	G	107	0.8	10	1,600	71.08	2.29	5.25	0.16	0.07	0.06				Off				•	•									
		31	TLD	L	107	0.8	10	1,600										Off														
		32	TLD, 28 VDC	D	71	0.8	10	1,600	0.95	0.29	3.80	0.01	0.24	0.24	583.452	0.005	0.014	Off			•											
		33	TLD, 400 Hz AC	D	194	0.8	10	1,700	0.95	0.29	3.80	0.01	0.24	0.24	524.821	0.005	0.013	Off	•						•							
Hydrant Cart	Used to connect underground fueling system to an aircraft.	34	Dukes THS-400	E	0	0.7	14	1,527										NA									Yes	Yes	Yes	Yes		Replacement for fuel trucks at airports with hydrants.
Hydrant Truck	Truck equipped system used to connect underground fueling system to an aircraft.	35	F250/F350	C	360	0.7	10	1,527										On									Yes	Yes	Yes	Yes		
		35	F250/F350	D	235	0.7	10	1,527	0.73	0.29	2.61	0.01	0.10	0.09	524.821	0.005	0.013	On	•	•					•	•						
		35	F250/F350	G	260	0.7	10	1,527	6.93	0.74	2.10	0.14	0.06	0.06	692.751	0.007	0.019	On														
		35	F250/F350	L	260	0.7	10	1,527										On														

Lavatory truck	Used to remove waste/non-potable water from aircraft lavatories.	36	TLD 1410	C	82	0.3	13		33.00	0.01	6.55	0.01	0.06	0.06	528.767	0.001	0.001	On									Yes	Yes	Yes	Yes		Commonly classified as "on-road" vehicles. Some airports use lavatory carts, which are pulled by tug.
		36	TLD 1410	D	56	0.3	13		0.66	0.27	2.41	0.01	0.07	0.07	583.452	0.005	0.014	On		•	•											
		36	TLD 1410	E	0	0.3	13											NA														
		36	TLD 1410	G	97	0.3	13		6.91	0.48	1.36	0.14	0.06	0.06	692.751	0.007	0.019	On														
		36	TLD 1410	L	89	0.3	13		33.00	1.41	6.55	0.01	0.06	0.06	550.260	0.000	0.000	On														
		37	Wollard TLS-770/F350	C	360	0.3	13		33.00	0.01	6.55	0.01	0.06	0.06	528.767	0.001	0.001	On														
		37	Wollard TLS-770/F350	D	235	0.3	13		0.66	0.27	2.41	0.01	0.07	0.07	524.821	0.005	0.013	On	•													
		37	Wollard TLS-770/F350	G	260	0.3	13		6.91	0.48	1.36	0.14	0.06	0.06	692.751	0.007	0.019	On														
		37	Wollard TLS-770/F350	L	260	0.3	13		33.00	1.41	6.55	0.01	0.06	0.06	550.260	0.000	0.000	On														
Lift	A lift has a carriage that can be moved by a motor upward and downward and that includes a platform.	38	None	C	132	0.5	11	341	33.00	0.01	6.55	0.01	0.06	0.06	528.767	0.001	0.001	Off									Yes	Yes	Yes	Yes		
		38	None	D	115	0.5	11	341	3.35	0.89	5.66	0.01	0.65	0.63	524.821	0.005	0.013	Off														
		38	None	G	105	0.5	11	752	77.94	2.21	3.98	0.15	0.07	0.06	692.751	0.007	0.019	Off														
		38	None	L	132	0.5	11	341	33.00	1.41	6.55	0.01	0.06	0.06	550.260	0.000	0.000	Off														
Other	N/A	39	None (EPA default)	C	173	0.5	10	1,017	32.52	0.01	6.36	0.01	0.06	0.06	528.767	0.001	0.001	NA									Yes	Yes	Yes	Yes		
		39	None (EPA default)	D	140	0.5	10	1,646	1.55	0.33	4.07	0.01	0.34	0.33	524.821	0.005	0.013	NA														
		39	None (EPA default)	G	126	0.5	10	868	84.57	2.42	4.35	0.15	0.07	0.06	692.751	0.007	0.019	NA														
		39	None (EPA default)	L	173	0.5	10	1,017	32.52	1.38	6.36	0.01	0.06	0.06	550.260	0.000	0.000	NA														
Passenger stand/stairs (truck mounted)	Provides passenger access/egress to aircraft.	40	Wollard CMPS170/CMPS 228	C	83	0.6	10	188	32.90	0.01	6.51	0.01	0.06	0.06	528.767	0.001	0.001	On									Yes	Yes	Yes	Yes	Nordco, NMC-Wollard, Victory GSE	Used mostly for air cargo, chartered and commuter aircraft.
		40	Wollard CMPS170/CMPS 228	D	65	0.6	10	188	0.73	0.29	2.60	0.01	0.10	0.09	583.452	0.005	0.014	On														
		40	Wollard CMPS170/CMPS 228	G	107	0.6	10	188	8.00	0.97	2.67	0.14	0.06	0.06	692.751	0.007	0.019	On														
		40	Wollard CMPS170/CMPS 228	L	107	0.6	10	188	32.90	1.40	6.51	0.01	0.06	0.06	550.260	0.000	0.000	On														

(continued on next page)

Table B-2. (Continued).

Type of GSE	Equipment Use	ID	Ref Model	Fuel	HP	LF	UL	Use[b]	CO	VOC[d]	NO_x	SO_x	PM_{10}	$PM_{2.5}$	CO_2	N_2O	CH_4	On/Off Road	Used by Aircraft Type[c]: Large Passenger – Wide Body	Large Passenger – Narrow Body	Commuter – Turboprop	Commuter – Jet	General Aviation – Jet	General Aviation – Prop	Large Cargo – Wide Body	Large Cargo – Narrow Body	Used At: Climate – Warm	Climate – Cold	Airport w/Gate Power & PCA	Airport w/ Underground Fueling	Representative Manufacturers	Notes
Service truck	Cleaning passenger cabins and replenishing on-board consumables or washable items.	41	F250/F350	C	360	0.2	10	369	33.04	0.01	6.56	0.01	0.06	0.06	528.767	0.001	0.001	On									Yes	Yes	Yes	Yes		
		41	F250/F350	D	235	0.2	10	840	0.59	0.25	2.09	0.01	0.05	0.04	524.821	0.005	0.013	On	•	•	•											
		41	F250/F350	G	260	0.2	10	369	7.99	0.97	2.67	0.14	0.06	0.06	692.751	0.007	0.019	On														
		41	F250/F350	L	260	0.2	10	1,931	33.04	1.41	6.56	0.01	0.06	0.06	550.260	0.000	0.000	On														
Snow removal equipment	Used to remove snow from runways, taxiways, and ramps.																	Off									No	Yes	Yes	Yes		Used at cold climate airports and some warm climate airports that experience snow occasionally.
Sweeper	Used to clean gate area and aprons.	42	Tennant	C	45	0.5	10	278	27.57	0.00	4.68	0.01	0.06	0.06	528.767	0.001	0.001	Off									Yes	Yes	Yes	Yes		Diesel-powered, specialty vehicles.
		42	Tennant	D	53	0.5	10	12	4.21	0.54	4.89	0.01	0.63	0.61	583.452	0.005	0.014	Off														
		42	Tennant	G	53	0.5	10	362	103.79	3.04	5.46	0.16	0.07	0.06	692.751	0.007	0.019	Off														
		42	Tennant	L	45	0.5	10	278	27.57	1.05	4.68	0.01	0.06	0.06	550.260	0.000	0.000	Off														

Water service	Used to supply potable water to aircraft.	43	Gate service	E	0	0.2	10	0										NA	•	•												Commonly classified as "on-road" vehicles.
		44	Wollard TWS-402-F250/F350	C	360	0.2	10	0										Off														
		44	Wollard TWS-402-F250/F350	D	235	0.2	10	924										Off									Yes	Yes	No	Yes		
		44	Wollard TWS-402-F250/F350	G	260	0.2	10	0	8.00	0.97	2.67	0.14	0.06	0.06	692.751	0.007	0.019	Off														
		44	Wollard TWS-402-F250/F350	L	260	0.2	10	0										Off														

LF = Load Factor   UL = Useful Life   D (Fuel) = Diesel   G (Fuel) - Gasoline   E (Fuel) = Electric   C (Fuel) - Compressed Natural Gas   L (Fuel) - Liquefied Petroleum Gas   HP = Horsepower   NA = Not applicable

[a] EDMS = Emissions and Dispersion Modeling System (Version 5.1.2)

[b] Usage per year in hours

[c] E = EDMS default assignments for passenger air carrier, commuter, and general aviation aircraft. Assumed assignments for cargo air carrier aircraft.

[d] Speciated organic gas air toxics emissions can be obtained by converting VOC emissions to TOG by multiplying by 1 for diesel powered GSE, or by 1.03 for gasoline, CNG or LPG powered GSE. The following speciation factors can then be applied to estimate the diesel powered GSE air organic gas/HAPs emissions: 0.0861 Formaldehyde; 0.0291 for acetaldehyde; 0.0177 propionaldehyde; and 0.0055 benzaldehyde. Alternatively, the following speciation factors can be applied to TOG to estimate the organic gas/HAPs emissions from gasoline, CNG or LPG powered GSE: 0..0175 benzene; 0.0091 0-xylene; 0.0067 ethylbenzene; 0.0186 m-xylene; 0.0298 toluene; 0.0153 n-hexane; 0.015 2.2.4-trimethylpentane; and 0.0073 n-heptane.

[e] Blank rows represent equipment for which EDMS does not currently report emission factors.

[f] EDMS does not directly provide GHG emissions factors nor does it directly compute GHG emissions from GSE. The factors were developed using methodology outlined in *ACRP Report 11*, and based on calculated fuel usage using EDMS parameters (for which fuel flow rates are available) and fuel-based emissions factors available through the U.S. Energy Information Administration.

Abbreviations and acronyms used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

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